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OCTOBER 2006

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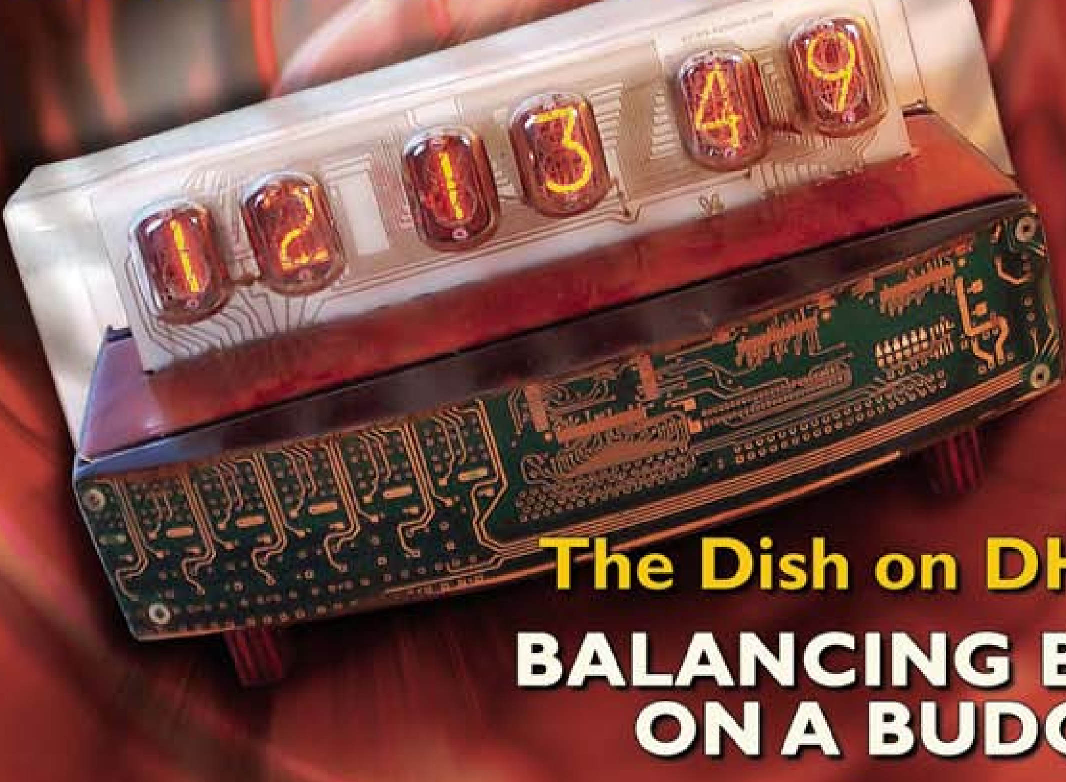


The Dish on DHCP

BALANCING BOT ON A BUDGET

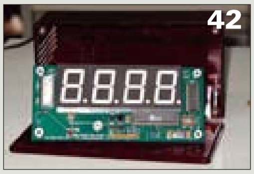
Power Line Frequency Monitor

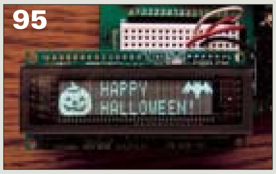
CLIMATE CONTROLLER

NUTS AND VOLTS

OCTOBER 2006

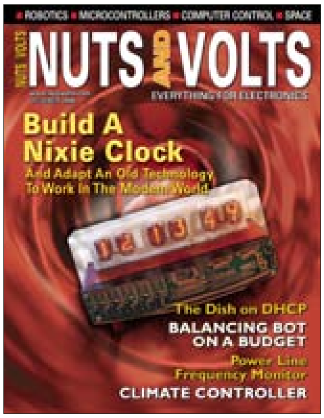
PROJECTS and FEATURES





ON THE COVER ...

BUILD A NIXIE TUBE CLOCK
Go back to the future with this "timely" project.



COLUMNS

DEPARTMENTS

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READER FEEDBACK

BETTER LATE THAN NEVER

I guess it was 30 years ago when I started getting really interested in electronics. I had only seen the second half of the original ELF article, and I wanted to build it so badly. I just couldn't get my hands on the rest of the information. I was only a kid (age 10) and didn't know about back issues then.

I've sort-of been kicking myself ever since for not being able to get my hands on that project. And after that, it seemed that "computers" were something secret because I just couldn't get all the pieces of the puzzle. Since it's RCA 1802, I'm not sure I'm going to build it, but it's nice to finally have the missing part of that article!! (Yeah, I'm sure I'll build it, just to have it. May not use it, but I'll build it!) I finally got my hands on a Z80 SBC and really took off from there.

By the way, those TIL311 displays are very hard to come by these days. Luckily, I have a personal stash of them. Maybe you need an adapter to connect to an LCD?? I don't know of an equivalent part, either. (I'm not even sure about the 1802.)

I feel like Dr. Frankenstein that has finally got the brain he needs to finalize his project ... Bwwwaaaaahaha!

Jack Steinhilper
Flowery Branch, GA

ON TARGET WITH ONLINE

As an electronics technician, I love the magazine. It's always full of fresh or refresher ideas that help me stay sharp and interested in electronics. I bring it to work sometimes and some of the guys like to look at it. I was actually introduced to your magazine by someone at work a few years ago and liked it so much, I subscribed to it. However, I do spend some time on the computer, so it would be nice to be able to log in as a subscriber and view the magazine online. Could you guys make this happen? Thanks!

Al Burningham
Slidell, LA

OOPS! I spoke too soon! I asked for an online version and I found it! Boy, you guys are good — you give me what I ask for, before I ask it. *Thanks, Al*

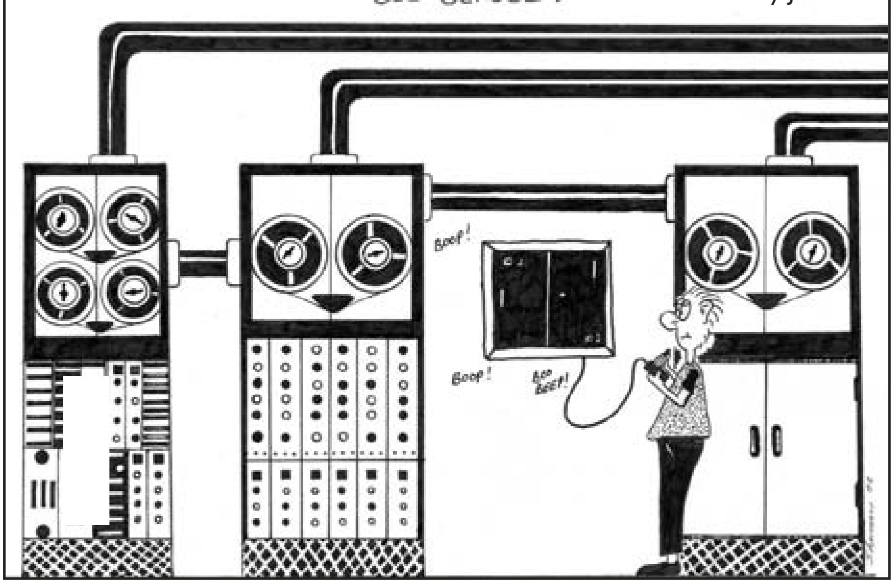
SPEAKING ON-RESISTANCE ...

The Near Space column in the July 06 magazine (and experiment with measuring on-resistance) provides an interesting question for readers. The data, so nicely graphed, also illustrate

Continued on page 109

OLD SCHOOL !

by J. Shuman



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FOUNDER/ASSOCIATE PUBLISHER
Jack Lemieux

PUBLISHER
Larry Lemieux
publisher@nutsvolts.com

ASSOCIATE PUBLISHER/ VP OF SALES/MARKETING
Robin Lemieux
display@nutsvolts.com

CONTRIBUTING EDITORS
Chuck Hellebuyck, TJ Byers, Jeff Eckert, Jon Williams, Peter Best, Dave Prochnow, Colin Barnard, Louis Frenzel, Ray Marston, Robert Lang, Thomas Henry, Jay Carter, Andrew Argyle, Robert Armstrong, Phil Davis, Brandon Heller

CIRCULATION DIRECTOR
Tracy Kerley
subscribe@nutsvolts.com

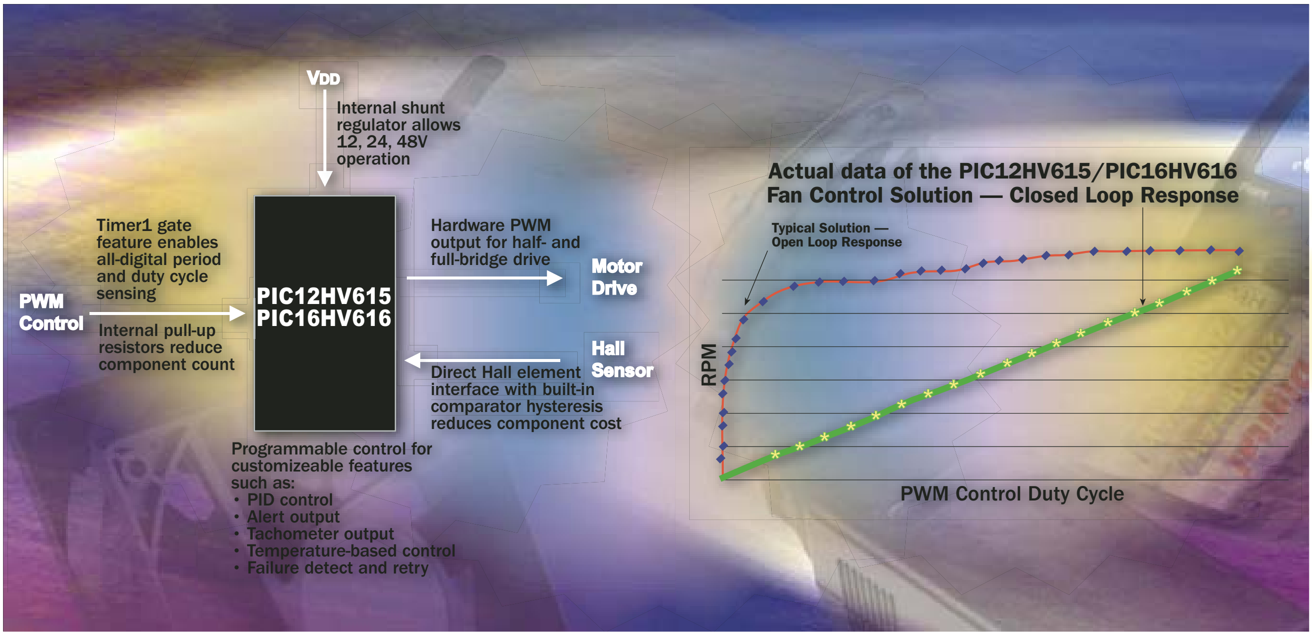
SHOW COORDINATOR
Audrey Lemieux

WEB CONTENT/NV STORE
Michael Kaudze
sales@nutsvolts.com

PRODUCTION/GRAPHICS
Shannon Lemieux

ADMINISTRATIVE ASSISTANT
Debbie Stauffacher

PIC12HV615/PIC16HV616 Closed Loop Fan Speed Control



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PIC16HV616	Yes	3.5 KB/2 Kw	8	2	Full bridge	8 MHz

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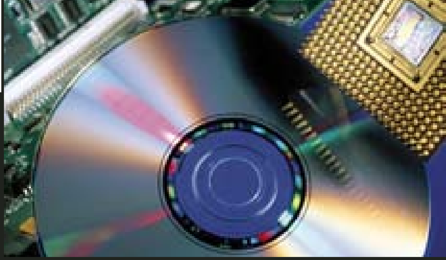


TECH KNOWLEDGEY 2006

EVENTS, ADVANCES, AND NEWS

■ BY JEFF ECKERT

ADVANCED TECHNOLOGY

LAKES DISCOVERED ON TITAN

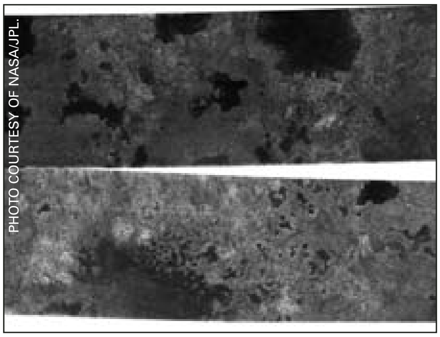


PHOTO COURTESY OF NASA/JPL.

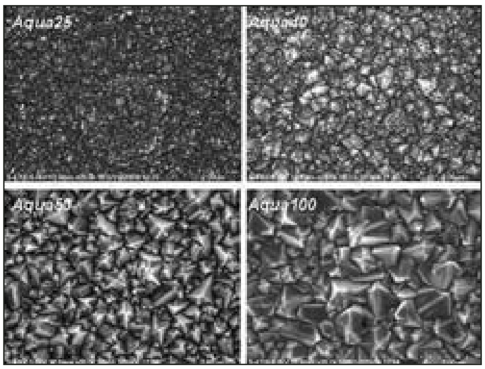
■ Radar images of lakes on the surface of Titan.

One of the most impressive packages of electronic sensing devices is the Cassini spacecraft, a six-ton voyager that carries several spectrometers, a cosmic dust analyzer, a magnetometer and magnetospheric imaging instrument, radar equipment, and the Radio Science Subsystem. It also originally carried the European Space Agency's Huygens probe, a self-contained robotic laboratory equipped with various instruments and sensors devoted to analyzing the atmosphere and surface of Titan — one of Saturn's moons. Early in 2005, Huygens successfully detached itself and landed on Titan, where it continues its work.

Now halfway through its four-year planned visit to Saturn, Cassini has already visited Venus and Jupiter and is now on a portion of its journey that will include 74 orbits and 44 close flybys of Titan. Among its recent discoveries is that Titan appears to be sprinkled with lakes all over its upper latitudes. You probably won't want to go snorkeling in them, though, as they are likely filled with liquid methane or ethane rather than water.

In the images, one can see channels leading in or out of the lakes, which implies that they were carved out by a liquid. Rings around the dark patches suggest that deposits might form as the liquid evaporates. This is particularly interesting, as no other body in the solar system — with the exception of Earth — is known to form lakes. For related details, images, podcasts, etc., visit **saturn.jpl.nasa.gov**.

A BUNCH OF FORKING DIAMONDS



■ Scanning electron microscope images of four varieties of UNCD Aqua series. Photo courtesy of ADT.

In coming years, we can expect vast improvements in telecommunication devices if ongoing research by Argonne National Laboratory (**www.anl.gov**) and several partners pans out. Under a $1.4 million Phase II R&D program funded by the Defense Advanced Research Project Agency (DARPA, **www.darpa.mil**), Argonne, Innovative Micro Technology, Inc. (**www.imtmems.com**), the University of Wisconsin-Madison (**www.wisc.edu**), and Advanced Diamond Technologies, Inc. (**www.thindiamond.com**), will be developing the concept of using ultrananocrystalline diamond (UNCD) in resonators and oscillators that will be integrated directly into microchips.

The aim is to create a variety of mobile technologies with much higher data communication rates. Because diamond — in addition to being the hardest known substance — is light and stiff, it can be used to produce tuning forks that vibrate at higher frequencies than those made up of other materials. In this case, we're talking about forks that are only about 100 nm long that vibrate at rates up to 100 GHz, as compared to the 850 or 1,850 MHz bands used by today's cell phones.

In Phase I of the program, it was determined that UNCD exhibits the highest known acoustic velocity, which translates to high resonator frequencies, and the frequency and the quality factor of such resonators are unaffected by environmental exposure, which is a highly desirable quality. The challenge is to figure out how to manufacture the diamond forks reliably and at a price that is not prohibitive. Phase II is scheduled to run 12 months, so stay tuned for progress reports.

COMPUTERS AND NETWORKING

QUAD-CORE DESKTOP INTRODUCED

Competition is tough in the US PC market these days, with the top two vendors hogging about more than half of the market (Dell, 32 percent, and HP, 19 percent). Gateway has been running a distant third with about six percent. It appears that

PHOTO COURTESY OF APPLE.

■ Apple's new Mac Pro is the fastest Mac ever built, and potentially the most expensive.

Apple (**www.apple.com**), which has been hovering at about three percent for several years, is moving up in the world, having sold more than 1.3 million Macs during the second quarter of this year, which translates into better than a five percent market share.

One of the reasons appears to be the switch to Intel chips, and the latest introduction in the line is the new Mac® Pro, a quad Xeon, 64-bit desktop workstation featuring two new Dual-Core Intel Xeon processors running up to 3.0 GHz, each with 4 MB of shared L2 cache and independent 1.33 GHz front-side buses. The machine runs up to twice the speed of the Power Mac G5 Quad and features 667 MHz DDR2 buffered memory and a 256-bit wide memory architecture for improved bandwidth. Plus, the box accommodates up to four drives for as much as two TB of storage.

The Mac Pro comes with OS® X version 10.4.7 Tiger, which includes Rosetta® translation software that lets users run most OS X PowerPC applications. But, as always, it will take a bite out of your wallet. The standard configuration, which runs at 2.66 GHz, lists at $2,499, not including a monitor. If you want to upgrade to the 3.0 GHz version, be prepared to shell out another $800. But if you're running short, you can drop to the 2 GHz unit and save $300.

Upgrading from the standard 1 GB of RAM to the maximum 16 GB will run you an extra $5,700, and add another $1,400 if you want all four 500 GB drives installed. Finally, you'll need a 20-, 23-, or 30-inch Cinema HD Display for $600, $999, or $1,999, respectively, so a nearly maxed-out computer could come to, um, $12,398.

NEW ENTRY-LEVEL WORKSTATION

For those of us who don't pack unlimited financial firepower, HP (**www.hp.com**) has introduced the xw4400 Workstation, aimed at meeting the demands of engineers, designers, video editors, and others who perform relatively intense computing jobs.

PHOTO COURTESY OF HEWLETT PACKARD.

■ HP's xw4400 Workstation offers good performance at an entry-level price.

Even though the starting price is less than $1,000, it features an Intel® Core™ 2 Duo or Core 2 Extreme processor and 975X Express chipset, dual graphics capabilities, and a range of graphics, memory, and storage options, including serial-attached SCSI hard drives. It comes loaded with Microsoft Windows® 32-bit or x64, is Windows Vista capable, and will offer Red Hat Enterprise Linux this fall.

Additional features include up to 8 GB of memory and 64-bit Extension Technology, which provides support for virtual memory addressing and the capability of running 64-bit operating systems and applications. It also comes with a three-year limited warranty, including parts, labor, and next business day on-site support, which should cover it from installation to obsolescence.

CIRCUITS AND DEVICES

PROJECTOR TURNS A WALL INTO A HOME THEATER

■ The MovieTime digital projector provides instant home theater.

PHOTO COURTESY OF OPTOMA.

This month's offering in the "neat stuff that I really don't need" category is the MovieTime™ DV10 digital projector from Optoma Corp. (**www.optomausa.com**). It's a portable (7.8 lb) digital projector with an integrated DVD player and speakers, designed to turn an empty wall into a home theater. The signal can come from the internal DVD or a variety of other sources, including video games and HDTV signals.

Using DarkChip2™ technology from Texas Instruments, the DV10 offers 1,000 lumens of brightness, a contrast ratio of 4,000:1, and an image size of 48 to 359 inches at projection distances of 4.9 ft to 32.8 ft (1.5 m to 10 m). The lens is a 1:1.11 manual zoom and focus, through which one can display 16 million colors. The internal audio can't be overwhelming, as it employs just two 5W speakers, but you can run the stereo out to another system, and it has an optical audio output for Dolby® surround sound.

An optional 50W subwoofer is available. The basic unit lists for $999, but as of this writing, a discount is available that brings it down to $925.

NEW CLASS-D AMPS FOR HANDHELDS

Aimed for low-power, small, portable electronics that require good sound quality are two new Class-D amplifiers from Analog Devices (**www.analog.com**). The SSM2301 (mono) and SSM2304 (stereo) Class-D amplifiers are designed to efficiently drive speakers in handheld and portable consumer applications by consuming minimal power, employing sigma-delta modulation to reduce electromagnetic interference (EMI), and integrating a filterless topology that eliminates external components.

According to Analog, the devices operate at 85 percent efficiency over a wide range of output power levels. The SSM2301 delivers 1.4W into an 8Ω load, and the SSM2304 delivers 2W of power into a 4Ω load. Both operate on a single 2.5V to 5.5V supply, have a micro-shutdown mode with a maximum shutdown current of 20 nA, and feature a built-in thermal shutdown and output short circuit protection. They are housed in tiny eight-lead, three-mm-square lead-frame chip-scale packaging (LFCSP), so you won't be hand soldering them into anything, but they may turn up soon in products that are assembled for you.

Other features include <1 percent THD plus noise when driving peak output loads from a 5V supply, and an SNR better than 98 dB. They operate in a range of -40°C to +85°C, and the price in 1,000-piece quantities is a mere $0.55.

INDUSTRY & THE PROFESSION

NESC UPDATES

If your work involves the National Electrical Safety Code® (NESC), you should note that it has been updated and is available through the Institute of Electrical and Electronics Engineers (IEEE, **www.ieee.org**). The code — which is used throughout the US and more than 100 other countries — offers practical guidance on safeguarding employees and the public when electrical supply and communication lines are designed, installed, operated, and maintained. It is updated every five years to reflect changes in the electrical and communications industries.

The 2007 code includes changes in many areas, including metal grounding poles, starting voltages and clearances, grounding and insulation for guys, clearances between transmission lines, multiplex cable attachment to neutral brackets, loading due to freezing rain and wind, arc exposure analysis, antenna radiation exposure limits, and others.

In addition, the 2007 code includes new appendices on loading and conductor movement, extreme wind loading, and maximum overvoltage at a worksite. The list price is $139 ($110 for IEEE members).

LOW-END CALIBRATOR INTRODUCED

If you have occasion to test and calibrate digital panel meters (DPMs), programmable logic controllers (PLCs), transmitters, sensors, or other devices requiring a 4 mA to 20 mA current loop signal, check out the model 420 from OTEK Corp. (**www.otekcorp.com**). It's just a simple instrument enclosed in a small (4 x 2.5 x 4 inch) box that clips onto your belt, but it can come in handy for no-frills field calibration.

It's powered by a 9V transistor battery and can drive loads up to 300 or sustain up to a 7V burden of the load. The device features a dual range of 19.99 mA and 25.0 mA and a 10-turn pot for precise setting. Rated at ±0.01 mA setting accuracy and stability from 0°C to 60°C, the model 420 lists for $149. **NV**

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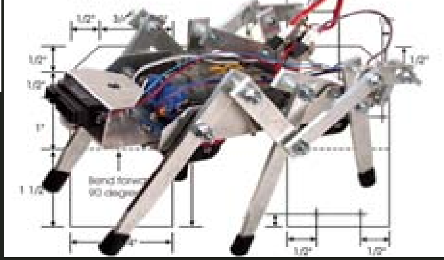


■ BY PHIL DAVIS and BRANDON HELLER

BUILDING A BALANCING BOT ON A BUDGET
Part 1 — Design Considerations

YOU WERE PROBABLY EXPECTING TO SEE Part 2 of the Saga of the Silver Bomber here, instead of this article on a Balancing Bot. To cut a long story short, we left off last month on the Silver Bomber motor controller, with everything designed and just waiting for parts. So, we waited and waited, but only about half the parts came in. Unfortunately, everything appears to be back-ordered, most likely due to the RoHS (Restriction of Hazardous Substance Directive) which is all about 'lead free' parts. With a bit of luck (not holding our breaths), all the parts should arrive in the next week or so, and we can finish and test the controller.

Meanwhile, I thought I would interleave this interesting project between the first and second parts of the motor controller article. By the way, this article will also have a second part, which will come directly after the completion of the motor controller.

Whew! Glad that explanation is over with. I am co-authoring this article with Brandon who is one of our Robotics Club members and is currently at Washington University working on a doctorate in Computer Engineering. I am so glad I get to co-author these articles with people who are smarter than me.

A balancing robot is something that has always fascinated me, and more than anything, it just seems like it's lots of fun and clever, to boot. Well over a year ago, Mike Keesling (the previous author of this column) and I wrote about a balancing bot based upon a single contact with the ground — a ball. Since then, several of these have been made, but they are way out of the budget and technical expertise of most hobbyists. We want to design something that most people not only can afford, but can also build from widely available parts.

WHAT IS A BALANCING BOT?

To understand what constitutes a balancing bot, we first direct our attention to the concept of *static stability vs. dynamic stability*. Static stability means that a robot has no need to actively correct its balance; its power can be turned off without it falling over. Dynamic stability, on the other hand, requires active balance correction. A third class of robots is a mix of the two categories. For example, a four-legged walking robot could remain statically stable when three legs are on the ground, but could require dynamic stability if the walking gait raised two legs off the ground at a time.

The vast majority of hobbyist robots are statically stable, including two-wheeled mini sumo robots, four-wheeled rovers, three-servo walkers, and many others. They're cheaper to build, easier to program, and have zero power consumption when stopped. Unfortunately, to maintain stability, they must be short, to keep the center-of-mass (COM) low, or if taller, must have a control system that limits movement speeds. For a robot designed to operate on steep terrain or interact with humans, these can be big limitations!

Dynamically stable robots eliminate these issues at the expense of greater complexity. Recent examples include the Segway, which maintains balance for its rider, the BalBot balancing robot kit, CMU's BallBot that balances on a single spherical wheel, and a number of humanoid robots.

In this first part, we'll discuss the design considerations of building a two-wheeled balancing robot, focusing on mechanical and electrical choices. Next time, we'll discuss the software architecture. Along the way, we'll learn a bit about the three required pieces for a balancing robot, which include sensing, control, and actuation. Sensing provides an estimate of robot tilt, control includes the algorithm for robot motion, and actuation is how we deliver power to the motors.

Designing and building a dynamically stable robot will prove to be an interesting challenge and learning experience. When all three

components are complete, we'll have a robot that balances by itself!

SENSING

We have a number of choices for a sensor to enable balance. One technique would be to sense the distance to the ground in front of the robot. If we know the distance at which the robot is vertical, we can try to have the robot maintain that distance to stay balanced. Infrared distance sensors like the Sharp GP2D12, sonar sensors like the Parallax Ping))) and Devantech SRF series, or even laser sensors can provide this distance measurement. The big issue is that this approach only works on perfectly flat surfaces! If we want the robot to go off-road, or even just go up ramps, we're out of luck.

Secondly, the update time is on the order of 10 ms for sonar sensors and 40 ms for the GP2D12. The performance of our control system may be limited by the speed at which we can get sensor updates, so we should be careful to pick a sensor that has low latency. We have to count out laser sensors as they're too expensive for the average hobbyist on a budget. The ground-sensing method might be an okay way to start off, as it is the cheapest, but we'll ultimately want something more robust.

Another type of sensing — inertial sensing — works in a totally different fashion: measuring acceleration. Linear accelerometers generally just go by the name of accelerometers, while those that measure angular accelerations are called gyroscopes, or gyros for short. By using these sensors to estimate tilt, we can balance the robot, regardless of the terrain around it. The challenge, as we'll see, is getting that tilt estimate to be robust to vibration and robot motion, and consistent over time.

THE ACCELEROMETER

To understand accelerometers, we'll use the example of a pendulum in a car, with a rock attached to a string. Accelerate forward and the rock swings backward; accelerate backward and the rock swings forward. This basic principle of a suspended mass reacting to changes in speed is used in today's accelerometers, but on a much smaller scale. Now, the deflection of a silicon beam is detected by a capacitive sensor, and the sensing and amplification components all fit on one tiny silicon die.

Using a method inspired by this principle 15 years ago, Analog Devices came out with the first MEMS (Micro Electro-Mechanical Systems) accelerometers, to sense deceleration in car crashes and trigger the airbags. These devices use manufacturing processes similar to those that produce computer chips, resulting in tiny, cheap, reliable, and low-power sensors. Since then, they've found applications in tilt-sensing game controllers, freefall detection to protect hard drive heads, and vehicle stability systems. Competition and economies of scale have reduced the prices to well within the range of hobbyists, even as most single chips now support two or sometimes three sensor axes.

The Analog Devices ADXL, Motorola MMA, MEMSIC MX, and Hitachi H48 series are all good choices, with different interface, performance, and cost specifications. The MEMSIC devices are particularly interesting, as they have no moving parts; instead of beam deflection, a tiny heater is used. Temperature sensors at the edges of the cavity measure the heat differential, which is proportional to the acceleration.

Now that we know how an accelerometer works, what is it that we'll actually be sensing? Remember that gravity is an acceleration that always points downward, with a magnitude of 1 G. Pointed down, our accelerometer will measure 1 G. Pointed forward, it'll measure 0 G. Pointed up, it'll measure -1 G. The component of gravity sensed by a forward-pointing sensor, for small angles near 0 G, is almost exactly proportional to the robot's tilt. We're not done yet; the reading is not always accurate. The accelerometer will sense the robot's forward motion, vibration, and even dips in rough terrain. The reading is accurate over time, as gravity will always point down with a force of 1 G, but we need something else to provide an accurate short-term estimate of tilt.

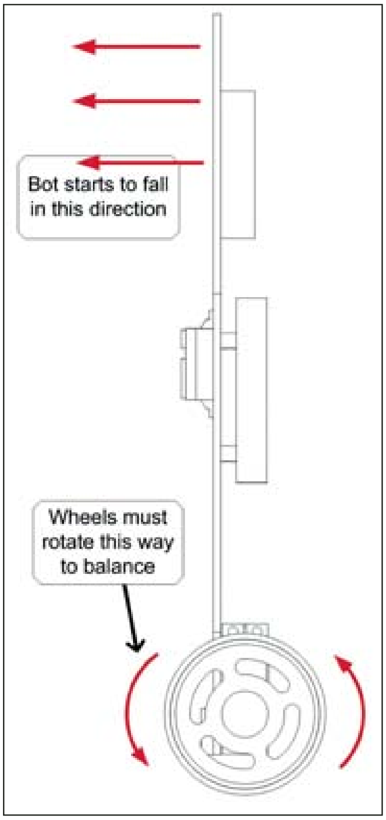
THE GYRO

Enter the gyro. They're highly accurate at providing a short-term estimate of tilt, so why not just use a gyro? A few reasons prevent us: First, there's no absolute indication of down, just a relative change from the previous angle. Second, the gyro provides a rate, which must be integrated over time to deduce the angle. Even if we measured the gyro thousands of times a second, at a precise interval, random noise would lead to an imperfect tilt estimate. Let's say we start the robot at zero degrees tilt, rotate it, and move it back to exactly zero degrees tilt. The tilt estimate will not be exactly zero degrees, and the greater the motion, the worse the "zero" estimate will get. Third, gyros drift over time. In other words, the voltage that represents zero degrees per second of angular rate will randomly change over time. Since we never know the exact voltage for zero motion, error will accumulate over time. Our robot would start balancing, but eventually the tilt estimate would become so skewed that it would fall over.

Fortunately, processes similar to those used to make accelerometers can now be used to make cheap, high-performance gyros. Examples include the Analog Devices ADXRS single-axis series, Silicon Sensing Devices CRS series, and the Invensense IDG3000 dual-axis gyro. DIP versions of these chips may not exist, so vendors have stepped in to provide prototyping boards with easier-to-use .1" headers, including Sparkfun, which has a huge range of breakout boards, and Parallax, which makes them for MEMISC and Hitachi parts.

SENSOR FUSION

Accelerometers and gyros are insufficient by themselves, but combined, are exactly what we desire. They yield an estimate of tilt that is accurate over both short and long time periods. This process of combining multiple sensors to provide better info than any single sensor is called sensor fusion. Inertial Measurement Units (IMUs) are an example, and are used in plane autopilots, vehicle stability controls, and even for providing updated position information when a GPS receiver can't locate



■ PHOTO 1. Wheels turn to move bot under COM.

enough satellites. A full discussion of techniques for fusing sensor data is outside the scope of this article, so we'll briefly mention the Kalman filter, a common solution.

A Kalman filter keeps an estimate of the current robot tilt, and uses the new sensor data to iteratively refine its estimate. The filter tracks uncertainty in each sensor to provide a theoretically optimal estimate of tilt. The math behind the Kalman filter can get complicated, but you don't need to know it! We'll pull code from the Internet to handle this task.

CONTROL

Now that we have an estimate of tilt, we need an algorithm, or sequence of steps, to balance the platform. In general, balance requires that we drive the wheels under the robot as quickly as possible (see Photo 1). There's more to it than that, though. We don't want the robot to move the wheels so fast that when they're directly under the robot they keep going. This is called overshoot, and results in oscillations and reduced stability. The control algorithm should minimize this overshoot, yet be robust to disturbances.

The simplest control scheme would be binary control, where the robot is driving the wheels forward or back at any given time, depending on the tilt. A slightly more sophisticated scheme would set the motor power to be proportional to the tilt:

motor_input = (tilt_error * p_gain) {P term}

This is a P loop, for proportional loop. The tilt error is the difference between the tilt estimate and the neutral angle, or angle at which the robot is balanced. The neutral angle will be nonzero if the robot's weight is not perfectly distributed over the wheel axles. The tilt error is multiplied by the P gain to form the P term. A high P gain will cause the robot to drive the motors to full power at a relatively small tilt error. The P gain lets us adjust the "stiffness" of the control loop. With just a P loop, our robot is likely to overshoot the balance position. As the wheels rotate, the robot starts to rotate towards balance, and as it approaches balance, there is nothing to slow it down. Thus, we add another term to the P loop:

```
motor_input =  (tilt_error      * p_gain)  {P term}
             – (angular_rate    * d_gain)  {D term}
```

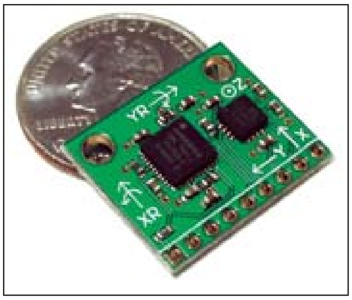
Now we have a PD loop, for proportional-derivative loop. The D term (rate times D gain) is from the gyro; it's the angular rate at which the robot is rotating. Note that the D term has a minus sign in front of it and opposes the P term as the robot gets to the near zero angle. The D term affects how the robot responds to disturbances. For example, if we push the robot when it is balanced, the tilt will be zero, and thus the P term will have no contribution, but the D term will be significant because the robot is in motion. Without the D term, the robot might take too long for the P term to have an effect, and could fall over. To help the robot stay in place, we add one more term:

```
motor_input =  (tilt_error      * p_gain)  {P term}
             – (angular_rate    * d_gain)  {D term}
             + (int_tilt_error  * i_gain)  {I term}
```

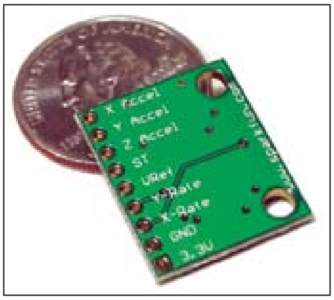
This is called a PID loop, for proportional-integral-derivative loop. The I term equals the integrated tilt error times the I gain. The integrated tilt error builds up over time; if the combination of P and D terms causes the robot to almost balance, but leaves it in motion with a slight tilt, the I term provides a kicker that brings the robot to vertical. At start, the integrated tilt error is set to zero, but on each algorithm update, it's updated.

It's possible to determine the P, I, and D gains theoretically, but we can do it experimentally, and it's a lot more fun that way. We'll start out with a small P gain, and increase it until the robot oscillates. Then, we'll dial back the P gain and try out different D gains until the robot balances well, even with disturbances. Finally, we increase the I gain to a value where the robot seems to hold its position the best. We'll leave the additional details of how to get the robot to intentionally move forward for next time.

■ PHOTO 2. Here is a front view of the Sparkfun IMU.



■ PHOTO 3. Here is a rear view of the Sparkfun IMU.



ACTUATION

The sensors and control algorithm are not enough; we need a way to deliver power to the wheels. We could use precision gearmotors or make our own gear reduction system; instead, we'll go with a cheap and readily-available motor, the hobby servo. Hobby servos, especially entry-level ones, aren't all that fast or powerful, but we'll try to rectify this with highly tuned software and sensors.

The motors will require a driver chip to deliver power.

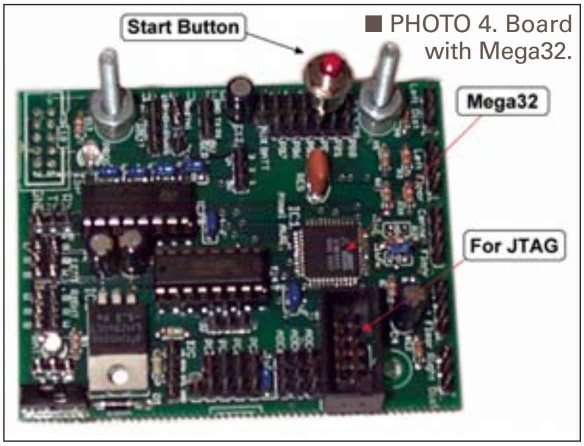
Frequent motor reversals are necessary for balance, so we'll be operating the motor near stall most of the time, which puts a severe strain on the drivers. We also want to be careful to design the electric system so that full battery voltage can reach the motors. This means using sufficiently thick wire and a battery chemistry with low internal resistance, such as NiCD, NiMH, or Lithium Polymer. Unlike alkalines, these battery types can deliver plenty of amps.

ROBOT DESIGN

So much for the theory of operation! To make all of this work, we need to select a set of components that will come close to matching what the theory dictates. Then we need to construct a platform to mount them on. As the title suggests, the bot should be built as much as possible on a budget so we will try as much as possible to use the cheapest, yet best components for the job.

The first thing to look at is the core of the whole project and that's the IMU. The particular IMU we chose is from Sparkfun and is a five degree-of-freedom device, consisting of a two-axis gyro and a three-axis accelerometer (see Photos 2 and 3). This terrific little device will form the complete sensing mechanism as described above in the theory of operations.

Now we need something to run our code. Hmmmm ... I know! Let's choose a Brandon Board. We use this fairly simple board extensively in our robotics club, and we've talked about it in previous articles. It has an Atmel Mega32 on board, a TI SN754410 IC motor driver, and a number of ADC inputs brought out to headers (see Photo 4). Obviously, you will not have access to one of these boards, but any reasonably fast CPU on a board available from many of the online robotic stores — such as BASIC Stamp, OOPic, or other AVR board — will work just as well. Before we forget, the Sparkfun IMU does require a 3.3 volt input. The Brandon Board has an onboard five-volt regulator, whose output we'll feed into a TI UA78M33C fixed-voltage regulator to generate the required 3.3 volts.



■ PHOTO 4. Board with Mega32.

Following our budget guidelines again, we want to use motors and wheels that are as affordable and accessible as possible. To this end, we have chosen standard RC servos which have been converted to continuous rotation and, on top of that, have basically been eviscerated of all electronics. Two of the three wires coming out of the servo run directly to the motor; the third is not connected to anything. This, of course, means that the servos have to be driven with PWM to obtain the required variations in speed. This is where the TI SN754410 comes in. Simple and effective. We will mount the basic MKII Mini Sumo 2.5 inch wheels onto these servos, which will give good speed and still have torque left over. We need motors that will move the wheels at a sufficient speed. If, for example, the bot is bumped, we have to hurry to get the wheels under the COM. In this case, if we can't go fast enough, the bot will fall. Balancing will be easiest if the motors yield a good reserve of speed and power.

To hold these selected components, some sort of chassis is needed, so we decided to cut some whiteboard on a laser printer. Besides being cheap, an interesting design can be

■ PHOTO 5. Matrix Orbital LCD.

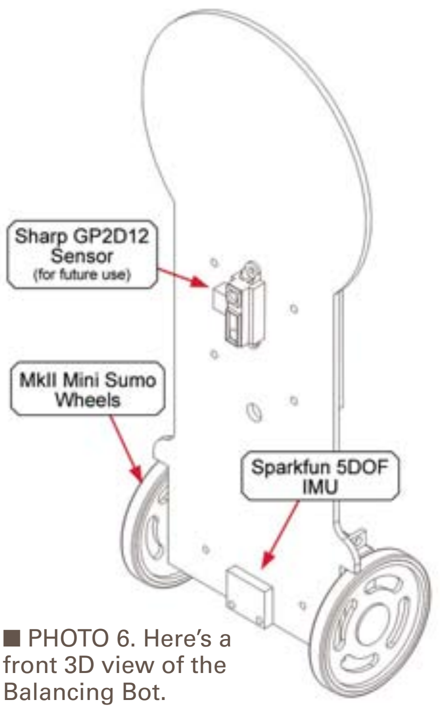
RESOURCES

■ Parallax, Inc. — **www.parallax.com**

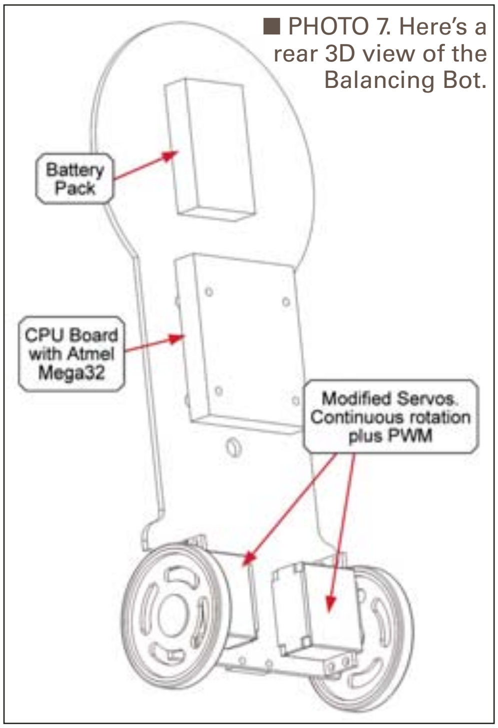
■ Sparkfun — **www.sparkfun.com/commerce/product_info.php?products_id=741**

■ Matrix Orbital — **www.matrixorbital.com/product_info.php?pName=lk20225wb&cName=lcd-characterlcds**

made; all the holes can be pre-cut and the resulting robot platform is clean, simple, and accurate.



■ PHOTO 6. Here's a front 3D view of the Balancing Bot.



■ PHOTO 7. Here's a rear 3D view of the Balancing Bot.

Another thing to make this a little easier is some way to see/watch all the tuning variables (P Term, I Term, P Gain, I Gain etc.) hopefully in real time, and, if possible, the ability to change them. To allow this to happen, we are going to connect an LCD device and display as much of the inner workings as we can (see Photo 5). We chose this pretty nifty LCD (#LK202-25-WB) from Matrix Orbital because it has both a serial and an I^2C interface, plus a lot of built-in smarts and a memory. With these specific features, writing to this device will be simple, considering everything else that will be going on.

IN CONCLUSION

That's it! We mocked up a 3D model of how the finished bot will look when finished — shown in Photos 6 and 7 — and next time, we will show you the code and describe all the tests and examples we went through to get it to balance. We will also publish a full listing of the code so you can make your own Balancing Bot in time for Christmas. **NV**

■ BY CHUCK HELLEBUYCK

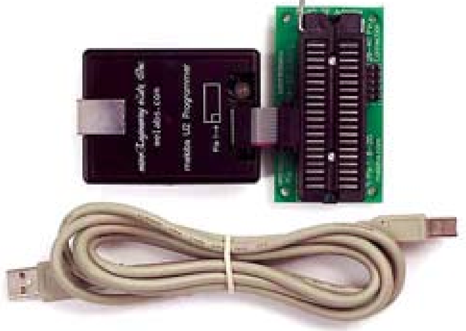
USB PIC PROGRAMMERS

THE EMAILS KEEP POURING IN AND IT'S GREAT. Easy and instant feedback is what makes the Internet so awesome. Though a few people let me know they feel I'm just writing this to sell my stuff, most understand that my goal is to help everyone I can learn how to develop microcontroller-based designs using PICs. I also get several emails from people who have discovered a different Basic compiler and wanted to let me know about its great features. If it gets you programming, then I say go for it. I use the Atom and PICBasic Pro the most so it makes it easier to write about them.

Since all these compilers are very similar, what you learn here should easily translate to the compiler you choose to use. I do keep up on what's out there so, in most cases, I have tried out the various compilers. Keep those emails coming though, maybe you'll introduce me to one I missed. If anyone out there is writing their own Basic compiler for PICs, I'd love to see that.

This time, I want to talk about something I don't yet offer on my website: a USB PIC programmer. Many people use laptops or newer computers that only have a USB port and they want to know more about USB PIC programmers. I haven't used them much until recently, so I thought I'd pass on some of my findings. There's no way I can cover all of them, but here goes.

■ FIGURE 1



MICROENGINEERING LABS

The same company that created the PICBasic Pro compiler recently introduced a USB programmer shown in Figure 1. As is usual with microEngineering Labs products, this programmer is well supported and programs most of the PICs. You can buy it as a raw, populated board or built into a nice plastic case. The programmer doesn't have a socket built in for the PICs, so it requires a separate board. microEngineering Labs did something very clever in that they developed a Zero Insertion Force (ZIF) socket that is laid out to program the 28 and 40 pin PICs with one connection and then the 8 to 20 pin PICs with a separate connection. This makes it very easy to reprogram PICs without bending the pins.

The connector used to connect the ZIF adaptor board is the same connector used on all their development boards that offer in-circuit serial programming. This allows you to hook up the USB programmer to the development board and program the PIC in-circuit without having to pull it out every time you find a code error.

The best part about this programmer is — like most USB PIC programmers — it's powered from the USB port. You don't need to add a high voltage power adapter to supply the 13V required by the PIC. The programmer creates all the signals needed from the USB port power. This makes it ultra portable and simple to use.

The cost of this programmer depends on how you purchase it. If you get it in the case with the ZIF adapter and the USB cable included, then microEngineering Labs lists it on their website for $144.95. If you can live without the plastic case, already have a USB cable that matches lying around, and only need to connect to a development board (no ZIF socket), then you can get one for $89.95. The one thing I can almost guarantee (based on my experience) is when Microchip releases a new PIC, microEngineering Labs will support it with updated software not long after.

One other feature of this programmer is it has a command line option, meaning it can be called from a batch file within an IDE. If you use Microcode Studio with PICBasic Pro, then you can one-click compile/program with this programmer. I often develop my code in one of my Ultimate OEM modules and then when it's ready, remove the bootloader define (DEFINE LOADER_

USED 1) and program a blank PIC through a PIC programmer. Using this programmer makes it a one-click operation. Though I often just use one of my EZPIC programmers since I have many of those lying around, this is making me rethink that process. It really works great.

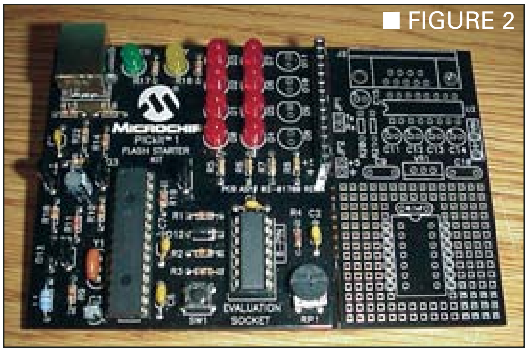


FIGURE 2

FIGURE 3

PICKIT1

Microchip released an application note #AN258 a while ago that describes how to build your own USB programmer for the 8/14 pin Flash PICs. You can buy that same programmer online at **microchip direct.com** called the PICKit1 programmer (Figure 2) and it comes with some interesting stuff. The free MPLAB software is included which is Microchip's official IDE for developing code. It also includes a version of the Hi-Tech PICC lite C language compiler if you want to try to learn C. You can also write in assembly language with these tools.

The programmer includes a PIC16F675 which is an eight-pin PIC with A/D and it supports many of the eight pin and 14 pin Flash PICs. The PICKit2 USB programmer from Microchip seems to be replacing the PICKit1, however, you can still buy it at **microchipdirect.com** for $36.

PICKIT2

The PICKit2 is really an interesting programmer. It can be purchased as just a programmer ($35) or you can get it with a 16F690 PIC and development board for $49.95 (shown in Figure 3). The PICKit2 programmer has a six pin header that sends all the signals needed to program a PIC, Vdd, Vss, Vpp (mclr), Data (typically B6), and Clock (typically B7) out to the header. The development board will work with any of the 20 pin, 14 pin, and eight pin PICs since they all have common pinouts. The PICKit2 software will also program many of the 18, 28, and 40 pin PICs, but you have to make a development board or jumper the connections.

The PICKit2 also adds a nice feature that allows you to power the development board from it. You can turn it on or off from the software used to download the code. Based on specs, I believe it will only supply 50 mA, but for most software development, this is plenty. You can also supply separate power to the board externally and just use the PICKit2 to program.

The development board included has a momentary switch, four LEDs, and a potentiometer all connected. There are also 12 sample projects written in assembly to get you started using these features. It's really a great setup to learn assembly programming with and it can also program the PICs with .hex files created by PICBasic Pro or a C compiler. This programmer doesn't offer a command line interface so you have to load the .hex file separately, but that's just a few extra mouse clicks.

Microchip has introduced an upgrade to the PICKit2. They call it PICKit2 Debug Express and you can see it at **www.microchip.com/pickit2** for $49.95. It has a new development board based on the PIC16F917 and allows you to debug your 16F917 code by setting a breakpoint, single stepping, and then running in animate mode. Expansion to other PICs is in the works.

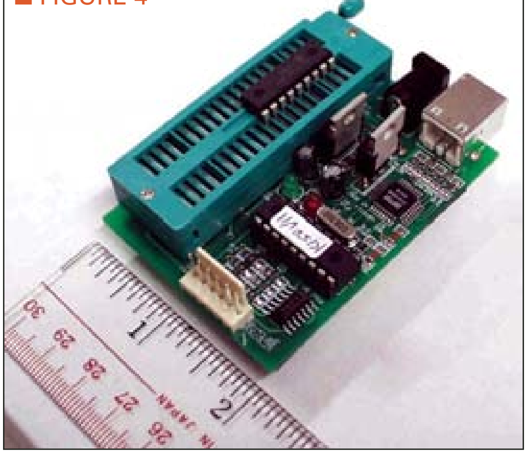
The debugger focuses on running assembly code and you need to use the MPLAB IDE which is free from **Microchip.com** (it comes with the PICKit1 and 2, as well), but if you write in assembly or even C, that is integrated into MPLAB, then you can easily step through your assembly or C code. I haven't had much luck getting Basic compilers to work with MPLAB and the debuggers, so that's why I focus on the MCStudio IDE for Basic language programming. If you ever figure out how to make any Basic compiler work with MPLAB and its debugger, shoot me an email quick.

USB KITS

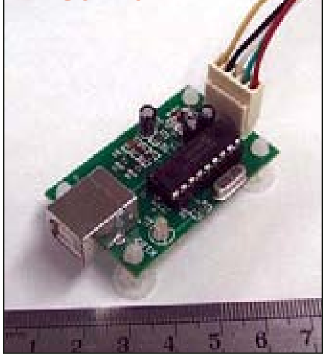
For those of you that are really into building your own programmer, one of the best kit sites I've found is **www.kitsrus.com**. They offer many different kits and sell them through various retailers. I went there to see what PIC programmers they offered and found a few. I have not tried these out, but I thought I would mention them.

Figure 4 shows a USB programmer that is a simple kit with most of the hard stuff already assembled. It's called Kit 150. You just have to plug in a chip and solder in the ZIF socket, based on what I read about it. I know

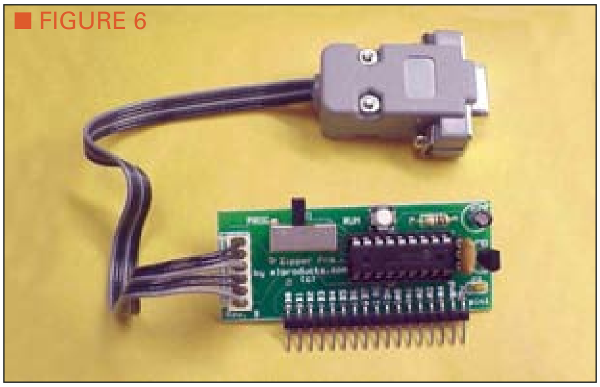
FIGURE 4



■ FIGURE 5



■ FIGURE 6



several people have talked about these on the various PIC chatrooms, so it seems to work fine. It also has an in-circuit serial programming header.

This USB programmer requires a 16V power supply, so if you have to add power, then that's another connection you'll have to deal with. That's one of the big reasons I like my EZPIC programmer over other serial port programmers — it gets power from the serial port.

KIT 182

This kit appears to be fully assembled, so it's not much of a kit. It's powered from the USB port which is great. The big difference is — as you can see in Figure 5 — this programmer doesn't have a socket for the PIC. It is strictly an in-circuit serial programmer. This isn't that much different than the **melabs.com** version or the PICKit2, except both of these offer a PIC socket board that attaches. You have to develop your own board to use this programmer or add jumper wires to your setup.

IN-CIRCUIT SERIAL PROGRAMMING

I quickly discovered that every one of these programmers — except the PICKit1 — offers a very simple in-circuit serial programming hook-up. This doesn't mean the PICKit1 can't program using this method, but it does require you to jumper wires from the PIC socket yourself. What I discovered is that there isn't a standard connection layout for the in-circuit programming header. I did find that the PICKit2 and the Olimex serial port version I use in my Zipper Pro module (shown in Figure 6) have the same pinout.

Since Microchip owns the PIC and Olimex has the same pinout, this appeared to me to be the closest thing to establishing a standard. I mention this because it's important to know what programmers are out there when you develop a PIC development board for your projects. You can make a conversion cable but that gets to be a hassle. You may want to just offer several different headers on your board so any programmer will work, but that takes up space. It's something to think about.

OLIMEX USB PROGRAMMER

Since this whole process brought me back to the Olimex programmers I use with my Zipper Pro, I decided to check out what **Olimex.com** has to offer and discovered their programmer shown in Figure 7. This programmer offers a USB connection with power derived from the USB port, so no power adapter is required. It also looks like a PICStart Plus programmer to MPLAB.

The PICStart Plus is Microchip's original serial port programmer, so with the Olimex version and MPLAB, this programmer could be a complete solution.

WHAT TO BUY?

I soon discovered I was only scratching the surface of USB programmers, but I feel the ones mentioned here are the cream of the crop. You'll have to determine which programmer is best for your specific needs.

If you are working with PICBasic Pro and the MCStudio IDE, then the melabs version appears to be the best option. If you are working with assembly or C (and don't mind loading the .hex file separately for PICBasic Pro), then the PICKit2 is very attractive. Especially since it's supported by Microchip, has the new debug feature, and supports most of the Flash PICs. If you want to learn assembly language, then the PICKit2 is my preferred choice.

If you currently have a PICStart Plus on a serial port, but want to move to USB, then the Olimex might be a great solution for an MPLAB integrated programmer.

Frankly, I'd like to own several of these programmers since each offers a unique feature. (Perhaps I can put these on my Christmas list. Programmers would be so much better than a tie!) Be sure to let me know your favorite "PIC." And keep those emails coming. **NV**

SOURCES

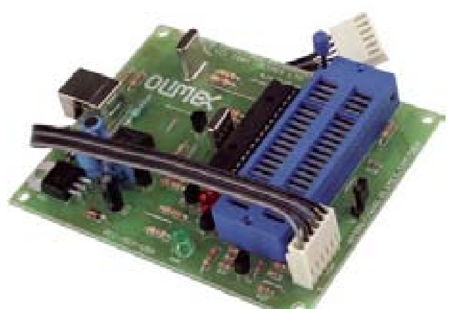
■ Chuck Hellebuyck's Electronic Products — **www.elproducts.com** *and* **chuck@elproducts.com**

■ microEngineering Labs
www.melabs.com

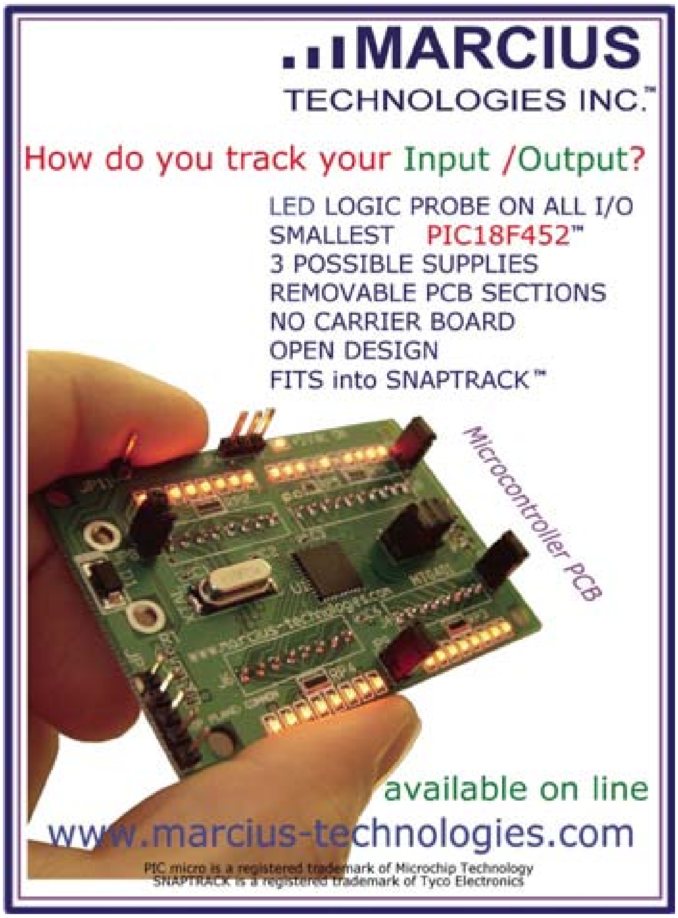
■ Microchip, Inc.
www.microchip.com

■ Kits R US
www.kitsrus.com

■ Olimex
www.olimex.com



■ FIGURE 7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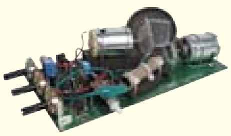

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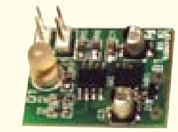

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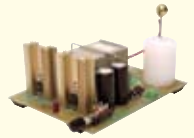

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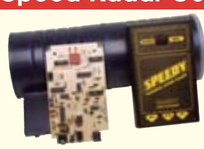

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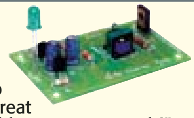
Tickle-Stick



The kit has a pulsing 80 volt tickle output and a mischievous blinking LED. And who can resist a blinking light! Great fun for your desk, "Hey, I told you not to touch!" Runs on 3-6 VDC

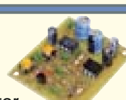
TS4 Tickle Stick Kit $12.95

Super Snoop Amplifier

Super sensitive amplifier that will pick up a pin drop at 15 feet! Full 2 watts output. Makes a great "big ear" microphone. Runs on 6-15 VDC

BN9 Super Snoop Amp Kit $9.95

Dripping Faucet



Produces a very pleasant, but obnoxious, repetitive "plink, plink" sound! Learn how a simple transistor oscillator and a 555 timer can make such a sound! Runs on 4-9 VDC.

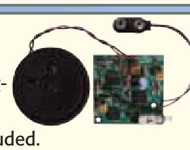
EDF1 Dripping Faucet Kit $9.95

LED Blinky

Our #1 Mini-Kit for 31 years! Alternately flashes two jumbo red LED's. Great for signs, name badges, model railroading, and more. Runs on 3-15 VDC.

BL1 LED Blinky Kit $7.95

Cricket Sensor



Senses temperature and changes the chirp accordingly. Can actually determine temp by chirps! Runs on 9VDC battery. Speaker included.

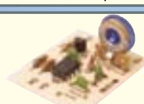
ECS1 Cricket Sensor Kit $24.95

Electronic Siren

Produces the upward and downward wail of a police siren. Produces 5W output, and will drive any speaker! Runs on 6-12 VDC.

SM3 Electronic Siren Kit $7.95

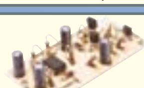
Universal Timer



Build anything from a time delay to an audio oscillator using the versatile 555 timer chip! Comes with lots of application ideas. Runs on 5-15 VDC.

UT5 Universal Timer Kit $9.95

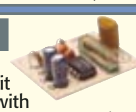
Voice Switch



Voice activated (VOX) provides a switched output when it hears a sound. Great for a hands free PTT switch, or to turn on a recorder or light! Runs on 6-12 VDC and drives a 100 mA load.

VS1 Voice Switch Kit $9.95

Tone Encoder/Decoder



Encodes OR decodes any tone 40 Hz to 5KHz! Add a small cap and it will go as low as 10 Hz! Tunable with a precision 20 turn pot. Runs on 5-12 VDC and will drive any load up to100 mA.

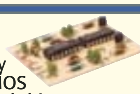
TD1 Encoder/Decoder Kit $9.95

RF Preamplifier

Super broadband preamp from 100 KHz to 1000 MHz! Gain is greater than 20dB while noise is less than 4dB! 50-75 ohm input. Runs on 12-15 VDC.

SA7 RF Preamp Kit $19.95

Touch Switch



Touch on, touch off, or momentary touch hold, your choice! Uses CMOS technology. Runs on 6-12 VDC and drives any load up to 100 mA.

TS1 Touch Switch Kit $9.95

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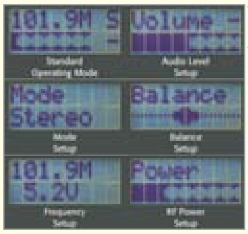
Where YOU become the DJ!

Digital FM Stereo Transmitters

- ✔ Rock stable PLL synthesized
- ✔ Front panel digital control and display of all parameters!
- ✔ Professional metal case
- ✔ Super audio quality!
- ✔ 25mW and 1W models!

For nearly a decade we've been the leader in hobbyist FM radio transmitters. Now for 2005 we introduce our brand new FM30 series of FM Stereo Transmitters! We told our engineers we wanted a new technology transmitter that would provide FM100 series quality without the advanced mixer features. They took it as a challenge and designed not one, but TWO transmitters!



The FM30 is designed using through-hole technology and components and is available only as a do-it-yourself kit, with a 25mW output very similar to our FM25 series. Then the engineers redesigned their brand-new design using surface mount technology (SMT) for a very special factory assembled and tested FM35WT version, with 1W output for our export market! Both are designed around an RF tight vinyl clad metal enclosure for noise free and interference free operation. All settings are done through the front panel digital control and LCD display! All settings are stored in non-volatile memory for future use.

Both the FM30 and FM35WT operate on 13.8 to 16VDC and include a 15VDC plug-in power supply. The stylish metal case measures 5.55"W x 6.45"D x 1.5"H and is available in either white or black. *(Note: The end user is responsible for complying with all FCC rules & regulations within the US, or any regulations of their respective governing body. FM35BWT is for export use and can only be shipped to locations outside the continental US or valid APO/FPO addresses or valid customs brokers for end delivery outside the continental US).*

FM30B	**Digital FM Stereo Transmitter Kit, 0-25mW, Black**	**$199.95**
FM35BWT	**Digital FM Stereo Transmitter, Assembled, 1W, Black**	**$299.95**

Professional Synthesized Stereo FM Transmitter

- ✔ Fully synthesized 88-108 MHz for no frequency drift
- ✔ Line level inputs and output
- ✔ All new design using SMT technology

Need professional quality features but can't justify the cost of a commercial FM exciter? The FM25B is the answer!

A cut above the rest, the FM25B features a PIC microprocessor for easy frequency programming without the need for look-up tables or complicated formulas! The transmit frequency is easily set using DIP switches; no need for tuning coils or "tweaking" to work with today's "digital" receivers. Frequency drift is a thing of the past with PLL control making your signal rock solid all the time - just like commercial stations. Kit comes complete with case set, whip antenna, 120 VAC power adapter, 1/8" Stereo to RCA patch cable, easy assembly instructions, and the SMT parts are factory preassembled - you'll be on the air quick!

FM25B	**Professional Synthesized FM Stereo Transmitter Kit**	**$139.95**

Tunable FM Stereo Transmitter

- ✔ Tunable throughout the FM band, 88-108 MHz
- ✔ Settable pre-emphasis 50 or 75 µSec for worldwide operation
- ✔ Line level inputs with RCA connectors

The FM10C has plenty of power to cover your home, back yard, or city block. You'll be amazed at the exceptional audio quality of the FM10C. Tunes through the entire 88-108MHz band. Re-broadcast your favorite music commercial free and with the dynamic range the musician intended, without all that nasty compression the big boys use to make their station sound louder than the competition. Compression produces a noticeably muddier and less dynamic sound. Runs on an internal 9VDC battery, external 5-15VDC, or our FMAC AC power adapter.

FM10C	**Tunable FM Stereo Transmitter Kit**	**$44.95**
FMAC	**110VAC Power Supply for FM10C**	**$9.95**

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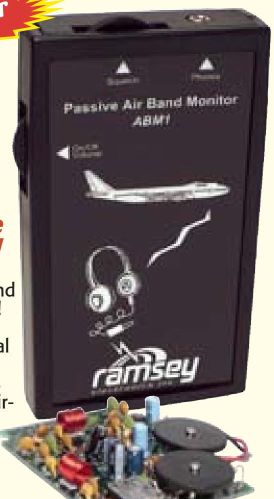
Passive Air Band Aircraft Monitor

New For 2006



- ✔ Monitors the entire aircraft band without tuning!
- ✔ Passive design, can be used on aircraft, no local oscillator, generates and creates no interference!
- ✔ Great for air shows
- ✔ Patented circuit and design!

Our Patented Design Has Now Made The Most Popular Kit In Our History!

For decades we have been known for our novel and creative product designs. Well, check this one out! An aircraft receiver that receives all nearby traffic without any tuning. It gets better... there is no local oscillator so it doesn't produce, and can't produce, any interference associated with all other receivers with an LO. That means you can use it onboard aircraft as a passive device! And what will you hear? The closest and strongest traffic, mainly, the one you're sitting in! How unique is this? We have a patent on it, and that says it all!

This broadband radio monitors transmissions over the entire aircraft band of 118-136 MHz. The way it works is simple. Strongest man wins! The strongest signal within the pass band of the radio will be heard. And unlike the FM capture effect, multiple aircraft signals will be heard simultaneously with the strongest one the loudest! And that means the aircraft closest to you, and the towers closest to you! All without any tuning or looking up frequencies! So, where would this come in handy?

1. ***At an air show! Just imagine listening to all the traffic as it happens***
2. ***Onboard aircraft to listen to that aircraft and associated control towers***
3. ***Private pilots to monitor ATIS and other field traffic during preflight activities (saves Hobbs time!)***
4. ***Commercial pilots to monitor ATIS and other field traffic as needed at their convenience***
5. ***General aircraft monitoring enthusiasts***

Wait, you can't use a radio receiver onboard aircraft because they contain a local oscillator that could generate interfering signals. We have you covered on that one. The ABM1 has no local oscillator, it doesn't, can't, and won't generate any RF whatsoever! That's why our patent abstract is titled "Aircraft band radio receiver which does not radiate interfering signals". It doesn't get any plainer than that!

SPECIFICATIONS

Frequency Range:	118 MHz to 136 MHz
Receiver Type:	Patented Passive Detector
IF Frequencies:	None!
Receiver Sensitivity:	Less than 2 uV for detectable audio
Audio Output:	700mW, 8-24 ohms
Headphone Jack:	3.5mm stereo phone, stereo earbuds included
External Antenna:	Headphone cord coupled
Power Requirement:	9VDC battery
Dimensions:	2.25" x 2.8" PC Board 2.5" x 4.6" x .9" Case
Weight:	4 oz. with battery

Available as a through-hole hobby kit for easy do-it-yourself assembly or a factory assembled & tested SMT version to operate right out of the box! The factory assembled version has become a favorite at air shows across the country. Just plug in the enclosed headbuds (or your favorite Walkman style headphones, and you're listening to all the activity on the ground and in the air!

Join in the excitement of monitoring your local aircraft the easy way, with our patented tune-free receiver!

ABM1	**Passive Air Band Monitor Kit**	**$89.95**
ABM1WT	**Passive Air Band Monitor, Factory Assembled & Tested**	**$159.95**

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Q&A

■ WITH TJ BYERS

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist.

Feel free to participate with your questions, comments, or suggestions.

You can reach me at: **TJBYERS@aol.com**

WHAT'S UP:

This month, our readers went wild with questions about theory applied to practical problems. And some practical problems needed background in theory.

- ✔ Powering the Ethernet.
- ✔ Internet call waiting.
- ✔ Lissajous and inductance.
- ✔ DOS is alive and well.
- ✔ Car radio solutions.

DOS: ALIVE AND WELL

Q In the June '06 issue in the section titled "Software On The Cheap," your answer says to create a MS-DOS boot disk. I have lots of MS-DOS programs. Can I run these programs from that boot disk after rebooting with that disk? I'm running XP and currently switching to a DOS window and/or full screen, but can't print from the window or full screen without screwing around with the clipboard. Any hope?

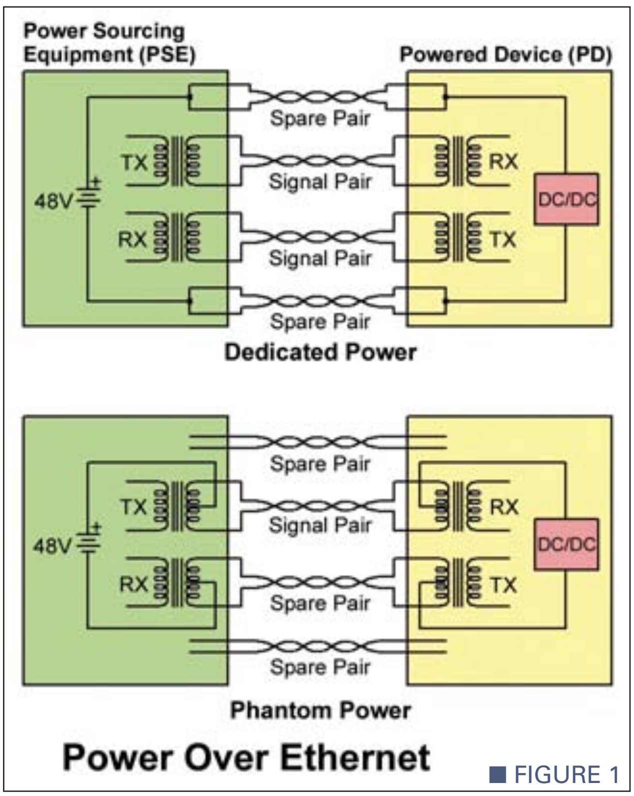
— Bob Kolhoff

A I really miss DOS because it lets you get to the heart of the PC using simple commands. It's still a solid operating system for dedicated PCs that monitor, control, and/or automate. Batch files are easy to create and QBasic is still a powerful, plain-English programming language. And yes, you can run your MS-DOS programs from a 3.5-inch DOS boot disk. I recommend version 6.22 because it was the last stand-alone DOS issued, and contains nearly 80 commands — along with a usable CD-ROM driver. Find a free download at **www.answersthatwork.com/Downright_pages/downrights_bootdisks.htm**

If you're working in XP, here's what I'd do. Create a CD-ROM DOS boot disk with all the DOS 6.22 files on it. There's even enough room to include the extended files (you can find all three extended file disks on eBay for under $10). Go into the PC's BIOS and set it to boot from the floppy first, CD-ROM second, and hard disk last. That way, you can override XP without having to create a separate boot section on the hard disk.

As for printing in DOS, DOS 6.22 defaults to ASCII printers only — like the old Epson dot matrix thrashing machines — not graphics. Look for the Print Screen (PrtScn) key. See **http://aroundcny.com/technofile/texts/tec091299.html** for details. For every other printer, you'll need a DOS printer driver.

Many DOS applications — like WordPerfect — have printer drivers that come along with the package. Simply pick your printer from those listed and follow the bouncing screens. Unfortunately, late model printers don't support DOS. But there is hope for DOS users who have a USB printer. It's called **www.bootdisk.com/usb.htm** Never tried it, but it appears solid.



■ FIGURE 1

POWERING THE ETHERNET

Q I have been working on building a wireless bridge between two buildings and have run into a problem with power-

ing the units. Running a 120 VAC outlet up a metal pole is probably not a smart thing to do. The solution is to use a Power over Ethernet (PoE) unit, which uses the CAT 5 cable to power the bridge units. But I have been unable to find a schematic example of these units. Can you show an example of these units?

— Daniel Borras
MTC Distributing, Inc.

A There are two IEEE802.3af standards used to route power over a CAT 5 cable. For insertion into an Ethernet line — called midspan — a dedicated pair is commonly used. In this configuration (Figure 1), the two spare pairs are connected directly to the 48-volt power source, and then converted down to 12V, 5V, 3.3V — or whatever.

If the PoE is built into the Ethernet switches — called endspan — the number of twisted pairs can be reduced from four to two using the phantom power configuration. This works because both the Power Sourcing Equipment (PSE) and Powered Device (PD) are transformer isolated. By applying the 48 volts to the center tap of the isolation transformers, the receiver has no problem sorting the data from the power.

The 802.3af requires the PSE to query the DP to see if it's PoE compatible or not. It does this by applying a small current-limiting voltage (less than 10 volts) to the cable and checks for a 25K resistor in the remote device. Only if the resistor is present is the full 48 volts applied to the PD. Even then, it's current limited according to PD class type (the max is 350 mA and 13 watts — Class 0). The device must continue to draw a minimum current (typically 5 mA to 10 mA). If it doesn't — like when the device is unplugged (802.3af is Hot-Swap) — the 48 volts will be removed.

That's the long and short of it. Since the ink has just barely dried on the spec, only a handful of dedicated PoE chips are available. Table 1 shows a sample of those available from sources like Digi-Key, Mouser, etc. — albeit they may not be in local stock and have to be special ordered at the moment.

Part No.	Function	Channels	Class ID	Input/Output
LTC4259	PSE	4	Y	I^2C in
MAX5945	PSE	4	Y	I^2C in
TPS2383	PSE	8	Y	I^2C in
LM5071	PD	1	Y	PWM out
LTC4257	PD	1	Y	ON/OFF out
MAX5942	PD	1	Y	PWM out
TPS2370	PD	1	Y	ON/OFF out

TABLE 1. PoE Chips.

THE FADE GOES UP, THE FADE GOES DOWN ...

Q I am a beginner just learning electronics. Can you tell me how to fade an LED up and down?

— Ngu

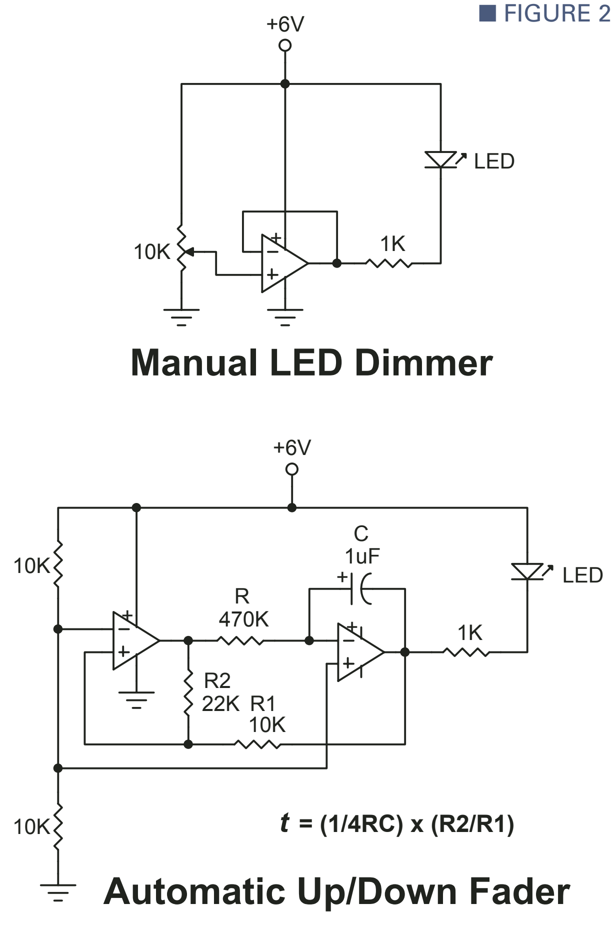
A LEDs are current operated devices, where the brightness increases as the current through the LED increases. The current through the LED is defined by a series resistor, where I = E - Vdiode / R. (A full discussion of LED operation can be found in the February '06 issue.) For the sake of this discussion, let's assume we have a red LED at full brightness, with a six-volt voltage source and a 1K current limiting resistor. Plugging the values into the formula, we get I = 6 - 2 / 1000 = 4 mA.

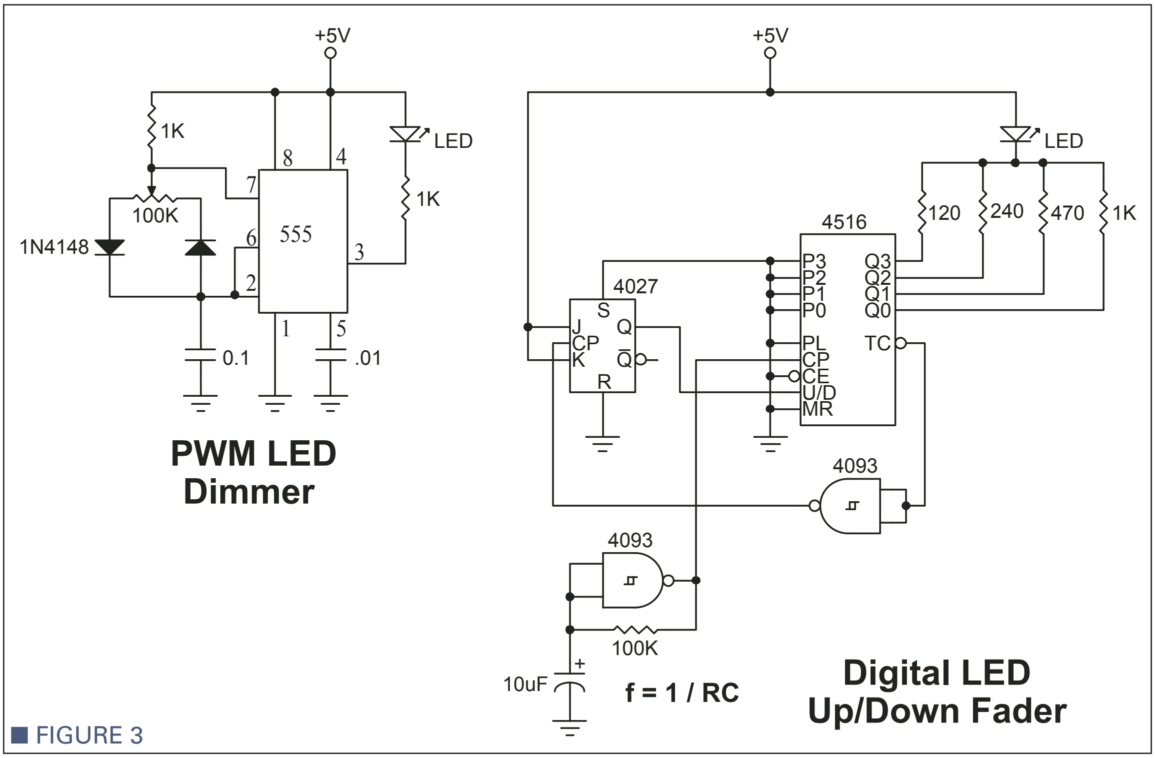
To reduce the brightness by one-half, simply reduce the voltage to four volts (I = 4 - 2 /1000 = 2 mA). This can be done manually using the potentiometer in Figure 2. The output voltage of the op-amp follows the voltage at the tap of the potentiometer, and controls the brightness of the LED. If you want to do this automatically, then you need to add another op-amp (Figure 2).

In this circuit, the first op-amp serves as a square wave oscillator. The second amp is an analog integrator that extracts a triangular wave from the square wave. When this slowly rising voltage is applied to an LED, it gradually brightens to full. On the downswing, it grows dimmer until it eventually goes off.

This method has the disadvantage of going dark when the input voltage goes below the LED's forward voltage. In the example above, the LED turns off once the declining voltage across the diode drops below two volts. And it stays off until the waveform voltage exceeds two volts — after which it

FIGURE 2





■ FIGURE 3

brightens to full and instantly starts dimming. The solution is pulse-width modulation (PWM).

With this technique, full voltage is always applied across the LED, so there is no "dead time." What causes the brightness to change this time is the width of the driving pulse. When the supply voltage is applied only 50% of the time, the LED appears — to the eye — to be half as bright. By varying the duty cycle of the voltage, we can go from off to full brightness without any dead time. Figure 3 shows a 555 timer circuit that lets you manually adjust the duty cycle from 0% to 100%.

The bottom circuit replaces the pot with a digital up/down counter. There are four outputs, each of which carries a weighted value. That is, when Q3 is on, it represents a current that's eight times (8x) more than the current value of Q0. Be placing equally-weighted resistors in series with the outputs and the LED, we create a perfect fade-on/fade-off effect. A single 4093 gate generates the clocking pulses. A 4027 J-K flip-flop changes the direction from count up to count down — causing the outputs to go from full off to full on and back again.

I'm sure you readers have your own LED fader circuits. If you wish to share your favorite with other readers, email them to me in PDF format and I will publish those I consider the most useful or unique.

INTERNET CALL WAITING

Q I miss quite a few telephone calls while I'm on the Internet. Do you have a simple circuit for a device I can hook up to my telephone line/computer that will signal me (with a blinking light) that someone is trying to reach me on the phone? I can then quickly log off and answer the phone.

— Bill
New York, NY

A I can't give you a simple circuit — but I can talk about commercial products that fill the bill. First, check with your Internet Provider (IP), some of which (AOL and PeoplePC, for example) offer this service for free or for a small surcharge. However, most Internet Call Waiting (ICW) software comes from third parties. The features vary all over the place.

Everybody has an alert pop-up, of sorts, that lets you know you have an incoming call. Sometimes you have to hang up and sometimes you can answer the call without going off-line. The amount of time you can talk before you're kicked of the Internet varies from a few seconds to a few minutes. For a few dollars more, the software will include an on-screen caller ID.

Other features may include an answering machine, voice message, or call forwarding. As a rule, the more features you choose, the more it will cost. Most of this software can be downloaded for a free 30-day test drive before you buy. Usually, you pay a monthly service fee between $1.50 and $10. But it pays to shop around because Phone Tray has a one-time price of $14.95 and BuzzMe charges just $14.95 a year.

Not comfortable with another monthly bill? Then look for a stand-alone hardware box or plug-in card. Once you shell out the big bucks, that's it. These devices work by listening for an incoming call and then notify you with a beep or blinking light. The prices start at about $40 and go as high as $200. As before, the more features you incorporate, the more it's gonna cost. But wait! There is a hidden fee not everybody talks about.

Whether you opt for a software or hardware solution, you need to have Call Waiting from your telephone company — which adds about $3.50 per month or so to your telephone bill. Want Caller ID? Yep, that's another fee. That's because all devices key on the signal(s) that the phone company provides with these features. These devices must detect those signals among all the other noise a

modem sends or receives. This is done using a microprocessor — either as a stand-alone device or by using your PC's CPU.

SOFTWARE
Phone Tray — $14.95 lifetime buy
http://phonetray.traysoft.com/index.htm

Buzz Me — $14.99/yr
www.buzme.com/

Web Call Waiting — $1.50/mo
http://webcallwaiting.com/?gclid=CLvd-ansrYYCFQx5WAod3HHrHg

Call Wave — $3.95 - $7.95/mo
www.slic.com/new/callwaiting_about.html#FAQs

AOL Call Alert — $7.95/mo
www.aolcallalert.com/Index.plt

HARDWARE
Catch-a-Call — $39.95 - $79.95
www.catch-a-call-online.com/catchacall-internet-call-waiting-manager.html

Zoom Model 3090DF V.92 USB Mini Modem — $50
www.zoom.com

Computer Peripheral Systems — $54 - $189
www.cpscom.com/cwp.htm

InTouch Internet Call Waiting Model 5000 — $79.99
www.classco.com/catalog.php

DOES ANYBODY KNOW WHAT INDUCTANCE IT IS?

Q I'm thinking of connecting a potentiometer in series with an inductor, then injecting a sine wave of a known frequency. Now, if I use an oscilloscope to observe the waveform across the resistor on channel A and the inductor on channel B and adjust the pot until the two are 45 degrees out of phase, would the value of the resistor be equal to the inductance?

— KJ4UO

A Actually, it will equal the inductive reactance (X_L) of the inductor — not its inductance. Like capacitors, the inductor changes AC resistance as the frequency varies. The higher the frequency, the higher the inductive reactance. Now if you insert a resistor in series with the inductor and vary the frequency to the point where the phase shift is 45 degrees, R will equal X_L. Conversely, if you keep the frequency fixed and vary the resistance until the phase shift is 45 degrees, again R will equal X_L. To find the inductance value, you need to run the numbers through the formula $L = R / 2\pi f$. Most test instruments measure inductive reactance at 1 kHz, but 60 Hz will work for chokes of 50 mH and larger.

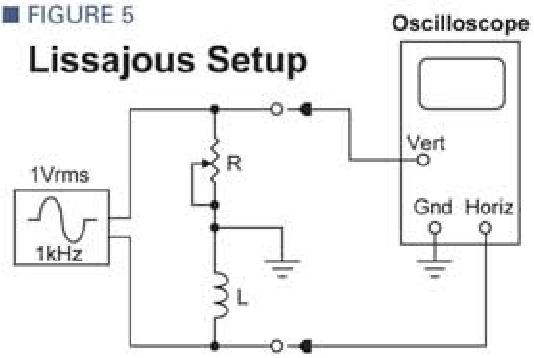
You can use your oscilloscope arrangement to determine the 45-degree point, but it's hard to eyeball that exact angle by comparing channel A to channel B. A better solution would be to compare the two signals using Lissajous patterns (Figure 4). In this arrangement, one signal is placed on the vertical input and the other on the horizontal input, as shown in Figure 5. A Lissajous pattern of 45 degrees is halfway between a straight line and a circle.

Don't have an oscilloscope? You can still measure inductive (or capacitive) reactance using a DMM on the AC range, as shown in Figure 6. Adjust the pot until the voltage across the pot and inductor are equal. Plug the values into the equation — and, vióla!

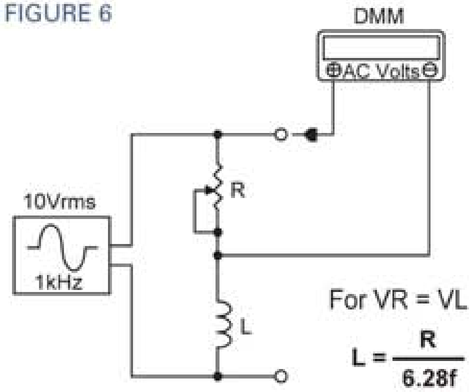
■ FIGURE 4

Lissajous Patterns

■ FIGURE 5



■ FIGURE 6



DMM Reactance Tester

MATCH MAKER — OLD TO OLD

Q I have an old truck that runs great ... but no radio. Is it possible to take a portable radio and put it in the truck and make it non-directional? Portables are okay until I turn a corner. I use AM exclusively. Is there some way to hook the portable up to the truck antenna?

— Richard

A Why not go to the junkyard and get an AM/FM dashboard radio from a 1990 or earlier wreck? They almost give them away. As for modifying a portable to use with the truck's external antenna: Wrap a few turns of

MAILBAG

Dear TJ,

In response to the answer you gave regarding the question from F Wan, of Ontario in the August '06 issue, you missed a VERY important step. Yes, you can use a Y-adapter to split the video signal, but now you will have two 75-ohm loads on that line, and the video will be dark. You would have to remove the 75-ohm load resistor from one of the devices. You can only connect one terminated load in a scenario such as this. The additional loads must be Hi-Z.

— Russell W. Kauffman
Beavertown, PA

Dear TJ,

In the July '06 issue you state (with regard to DVD formats): "Write once is self-explanatory. You can write to the disc only one time and one time only. You can't add stuff later." This is incorrect. While anything written to one-time media can't be changed, DVD formats for the past couple of years have supported multi-session writing on one-time media. A burner that supports multi-session DVD lets you add material to a DVD — provided that the original writing was done as a multi-session and the disc is not full. DVD readers also need to support this explicitly or they will only see the first session.

— Barry Watzman

#24 wire around the ferrite rod, ground one end and attach the other end to the antenna. For best results, point the ferrite rod up and down vertically rather than horizontally. That'll prevent loud and soft reception as you corner.

Reader feedback: I did as you suggested and bought a junkyard radio and it works great! I also tried your suggestion of wrapping a few turns around the ferrite rod — and found it generated a lot of engine noise. No matter what I did, it wouldn't go away. Like I said, it's an old truck. — Richard

COOL WEBSITES

Still trying to get the hang of that digital camera? This website will answer the basic questions about digital photography — including the myth about DPI and print quality.

www.rideau-info.com/photos

Want to try VoIP — Voice over Internet Protocol — but don't know where to start? Try these two free telephone web services.

www.skype.com
www.jajah.com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www.atomictime.com
Quantity discounts available!
WS-8248 - $64.95
WS-9412U - $19.95
LaCrosse WS-9412U Clock $19.95
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Tell time by the U.S. Atomic Clock -The official U.S. time that governs ship movements, radio stations, space flights, and war-planes. With small radio receivers hidden inside our timepieces, they automatically syncronize to the U.S. Atomic Clock (which measures each second of time as 9,192,631,770 vibrations of a cesium 133 atom in a vacuum) and give time which is accurate to approx. 1 second every million years. Our timepieces even account automatically for daylight saving time, leap years, and leap seconds. $7.95 Shipping & Handling via UPS. (Rush available at additional cost) Call M-F 9-5 CST for our free catalog.


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WWW.PCBCART.COM


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Connectors & Adapters
As Low As $0.40
100's of Kit Projects
Halloween Pumpkin Only $9.95
MK145
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New Product
USB PC 2 CH 60MHZ Oscilloscope
Includes 2 Probes! $334.95
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NEW PRODUCTS

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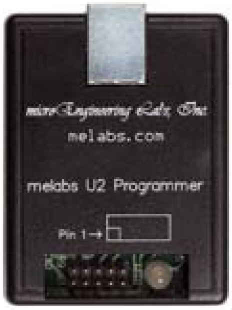
- SOFTWARE
- GADGETS
- TOOLS

U2 PROGRAMMER **FOR PIC®** MICROCONTROLLERS



MicroEngineering Labs, Inc., has released a new USB programmer for PIC® microcontrollers. The melabs U2 Programmer will program over 300 different PIC MCUs, including dsPIC® devices. Supply voltages are automatically adjusted for each device, allowing you to program 5V microcontrollers and the newest devices that run at 3.3V.

A USB connection to your PC is all that's needed to operate the programmer. No external power is required, making it ideal for portable use with a laptop. Lead-free fabrication makes the programmer RoHS compliant and environment-friendly.

Designed with in-circuit programming in mind, the programmer features a convenient 10-pin header that can be connected to a target board. Programming in-circuit speeds the development process and allows you to program a surface mount device that is soldered in place. The programmer isn't limited to in-circuit operation. Adapters are available for programming individual PIC microcontrollers in through-hole and surface-mount packages up to 80 pins. You can purchase the programmer with an accessory bundle which includes an adapter for eight-pin through 40-pin DIP packages.

Windows software is included with the programmer. It accepts standard Microchip format .HEX files that are generated by MPLAB, C compilers, and BASIC compilers. Command line options allow the programmer to be controlled from a batch file or shortcut for production use.

The software is loaded with selectable options, allowing you to customize your interaction with the programmer. A detailed memory view shows you each region of memory in the microcontroller. The PIC MCU's configuration bits can be set with convenient dropdown selections.

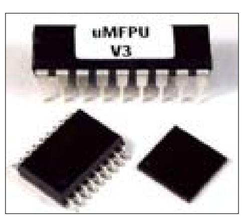
The melabs U2 Programmer is available in several package choices starting at $89.95. It can be purchased with or without a plastic enclosure, by itself, or with accessories.

For more information, contact:
microEngineering Labs, Inc.
Box 60039
Colorado Springs, CO 80960
Tel: **719-520-5323**
Fax: **719-520-1867**
Email: **sales@melabs.com**
Web: **www.melabs.com**

uM-FPU V3 FLOATING POINT COPROCESSOR

Micromega Corporation has released the uM-FPU V3 Floating Point Coprocessor chip. The uM-FPU V3 chip interfaces to virtually any microcontroller using an SPI interface or I^2C interface, making it ideal for microcontroller applications requiring floating point math, including sensor readings, robotic control, GPS, data transformations, and other embedded control applications.

The uM-FPU V3 chip supports 32-bit IEEE 754 compatible floating point and 32-bit integer operations. The new chip is 10 to 20 times faster than previous versions for all instructions, and up to 70 times faster for advanced instructions. New instructions provide support for faster data transfer, matrix operations, multiply and accumulate, unit conversions, and string handling. Two 12-bit A/D channels are provided that can be triggered manually, by external input, or from a built-in timer. A/D values can be read as raw values or automatically scaled to floating point values. Local data storage has been expanded to include 128 general-purpose registers, eight temporary registers, 256 EEPROM registers, and a 256 byte instruction pipeline.



An Integrated Development Environment (IDE) makes it easy to create, debug, and test floating point code. The IDE code generator takes traditional math expressions and automatically produces uM-FPU V3 code targeted for any one of the many microcontrollers and compilers supported. The IDE also supports code debugging and programming user-defined functions.

User-defined functions can be stored in Flash using the IDE, or stored in EEPROM at run-time. Nested calls and conditional execution are supported. User-defined functions can provide significant speed improvements and reduce code space on the microcontroller.

The uM-FPU V3 is RoHS compliant and operates from a 2.7V, 3.3V, or 5V supply with power saving modes available. SPI interface speeds up to 15 MHz and I^2C interface speeds up to 400 kHz are supported. The chip is available in an 18-pin DIP, SOIC-18, or QFN-44 package at a single unit price of $19.95 with volume discounts available.

For more information, contact:
Micromega Corporation
1664 St. Lawrence Ave.
Kingston, ON K7L 4V1
CANADA
Tel: **613-547-5193**
Web: **www.micromegacorp.com**

LEAD FREE TABLE TOP CONVECTION REFLOW OVEN

LPKF Laser & Electronics has released the new bench-top LPKF ProtoFlow Oven for lead-free reflow soldering, in addition to its wide range of PCB prototyping equipment. The new design has been greatly influenced by the new stringent process requirements of lead-free technology, as well as by the prior oven model from LPKF, the ZelFlow R04.

Maximum process temperature is 320°C/608°F and as a standard feature, the oven incorporates four internal temperature sensors and a multiprocessor controller board, which together ensures even heat distribution over PCBs up to 9 x 12 inches. Several software zones between preheating and final reflow make the LPKF ProtoFlow capable of processing most all reflow profiles, as well as making it an ideal oven for prototyping, technology research, and even pre-production testing.

Four additional optional sensors can be freely mounted on the PCB by the operator, enabling the on-board temperature to be recorded and displayed in real time on a PC through a standard USB connection, assisting the operator with process parameter optimization. Furthermore, the reflow process can be observed through a large window.

The LPKF ProtoFlow is a user-friendly reflow oven with many pre-programmed process profiles, which can be easily selected using four navigation keys. Custom profiles may also be created on a PC which may then be uploaded to the ProtoFlow oven. An LCD display, together with an intuitive software interface, completes the control features of this oven. Process parameters can be exchanged with a PC and conveniently managed and archived. Microsoft Excel can be used to monitor and document progress parameters for complete quality management documents.

For more information, contact:
LPKF Laser & Electronics
Tel: **503-454-4212**
Fax: **503-682-7151**
Web: **www.lpkfusa.com**

MULTI-FUNCTION CCTV TESTER

The Rapport337 Multi-Function CCTV Tester with 2.5" LCD Monitor (MCM part #82-11560) is an innovative, portable, hand-held tester that combines six primary functions into a single, easy-to-use device. It provides most of the testing functions for installation and maintenance of CCTV system in one compact, battery-operated, portable device.

Features of the Rapport337 Multi-Function CCTV Tester include:

- 2.5" Color LCD Field Monitor to adjust camera focus and angle
- Video Signal Generator to test monitor's color, brightness, and contrast
- Full-Function DMM tests voltage, current, resistance, and continuity for both AC and DC current
- PTZ Protocol Analyzer can determine the protocol of most PTZ cameras
- PTZ Controller to program PTZ cameras
- UTP Cable Tester identifies opens and shorts for both straight-through and crossover UTP/SPT cables
- Comes complete with six "AA" Ni-MH batteries, AC adapter/charger, DC charger, BNC patch cable, UTP terminating module, test leads, and case

With a suggested list price of $549, the Defender Security Rapport337 is affordable, convenient, and easy to use. It is designed to help installers and engineers utilize their work effectively at a reasonable price.

For more information, contact:
MCM
Tel: **800-543-4330**
Web: **www.mcminone.com**

VINCULUM USB HOST CONTROLLERS

Future Technology Devices International Ltd. (FTDI) has announced the release of the Vinculum family of embedded USB Host Controller devices. The Vinculum USB host controller ICs handle the USB host interface and data transfer functions. With a built-in 8/32 bit MCU and embedded Flash memory, Vinculum encapsulates the USB device classes, as well.

When interfacing to mass storage devices such as USB Flash drives, Vinculum transparently handles the FAT File structure communicating via UART, SPI, or parallel FIFO interfaces via a simple-to-implement command set. Target pricing is $5 each @ 10K pieces.

The initial product member of the family is the VNC1L device, which features two USB ports that can be individually configured by firmware as host or slave ports. Key VNC1L features include:

- 8/32 bit V-MCU core
- Dual DMA controllers for hardware acceleration
- 64K Embedded Flash program memory
- 4K internal data SRAM
- 2 x USB 2.0 Slow/Full speed host/slave ports
- UART, SPI, and Parallel FIFO interfaces
- PS2 legacy keyboard and mouse interfaces
- Up to 28 GPIO pins, depending on configuration
- 3.3V operation with 5V safe inputs
- Low power operation (25 mA running/2 mA standby)
- Built-in FTDI firmware easily updated in the field
- LQFP-64 ROHS compliant package
- Multi-processor configuration capable

"Vinculum brings cost-effective USB host capability to products that previously did not have the hardware resources available. We anticipate that these devices will be especially popular for adding USB Flash drive connectivity to a wide range of consumer and industrial products. As Vinculum comes complete with FTDI's in-house developed firmware, there are no USB software stacks to license, indeed, no knowledge of USB is required to use these devices," comments FTDI's CEO, Fred Dart.

"Vinculum, derived from the Latin word 'vincere' means 'an entity that binds/ties objects or expressions together' — in our case, various USB

and other technologies."

Complete details for the Vinculum VNC1L are located at **www.vinculum.com**. FTDI's full product line can be found on the website listed below.

For more information, contact:
Future Technology Devices International Ltd.
5285 NE Elam Young Pkwy.
Suite B800
Hillsboro, OR 97124
Web: **www.ftdichip.com**

DIPTRACE 1.23
BOASTS INTUITIVE USER INTERFACE

Novarm Limited now offers the DipTrace 1.23 — an advanced PCB design software application that comes with a PCB layout module, a powerful auto-router, schematic capture, and component/pattern editors to design your own component libraries.

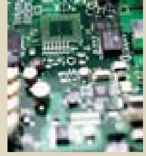
Besides being simple to learn, DipTrace has a very intuitive user interface and many innovative features. For instance, a schematic can be converted to a PCB with one mouse click. The board designer can instantly renew the PCB from an updated version of the schematic and keep existing placement, routed traces, board outline, mounting holes, and other work.

DipTrace has a high quality automatic router, which can route a single layer (bottom side) and multilayer circuit boards. There is an option to autoroute a single layer board with jumper wires, if required. Smart manual routing tools allow users to finalize the design and get the results they want quickly. DipTrace has an accurate, shape-based copper pour system with different possible fill types and thermals to make a ground plane layer or to reduce manufacturing costs by minimizing the amount of etching solution.

Another important feature is Design Rule Check (DRC) — the function that checks the clearance between design objects and the minimum size of tracks and drills, which ensures board accuracy. A net connectivity function allows you to check all electrical connections and find all broken nets and their isolated areas. A feature comparing a PCB to a schematic helps detect possible design mistakes and correct them before prototyping. Output formats are DXF, Gerber, N/C Drill, and G-code. DipTrace allows you to import DXF files into a PCB layout and pattern editor. Standard libraries contain 50.000+ components.

The unlimited version of DipTrace is available for US$695, DipTrace Extended (2,000 pins), DipTrace Standard (1,000 pins), and DipTrace Lite (500 pins) are available for US$495, US$345, and US$145, respectively. There is a free version available for students and hobbyists with a 250 pin limit. Full-featured 30-day trial and free versions with the 250-pin limit are available at Novarm's website listed below.

For more information, contact:
Novarm Ltd.
166 Rabochaya Str, Suite 19
49008 Dnepropetrovsk
UKRAINE
Tel: **+1-810-637-4764**
Web: **www.diptrace.com**



THIS MONTH'S PROJECTS

LEVEL RATING SYSTEM

To find out the level of difficulty for each of these projects, turn to our ratings for the answers.

- . . . . Beginner Level
- . . . . Intermediate Level
- . . . . Advanced Level
- . . . . Professional Level

BACK TO THE FUTURE WITH NIXIES

The Nixie tube represented the pinnacle of display technology in the 1950s and 1960s.

Nixie tubes were widely used and available in stores and electronics outlets such as RadioShack. There is something magical about adapting an old technology to work in the modern world. Fragile and beautiful Nixie tubes are worthy of displaying once again.

Unlike LEDs and LCDs, Nixie tubes are pretty objects made of glass that display glowing numbers or letters — perfect for "count-downs." Their visual appeal has been embraced by moviemakers who have employed Nixie tubes as count-down devices of bombs about to explode.

The most popular way of using Nixie tubes today is in the form of clocks — where the tubes are used to display the hours, minutes, and seconds.

What is a Nixie Clock?

Modern Nixie clocks are blends of old and new technology. The Nixie tube was invented in the 1950s to give an easily-read representation of numbers and some common electrical symbols. Nixie displays are still identifiable since almost all b-grade and science fiction movies of a certain age use them to show "science" in their movies. Modern clocks use the pleasing color and look of the glass tubes to give a "retro" look to otherwise bland looking modern clocks.

The Nixie tube is a different type of display since it was invented in an era when high voltage devices were much more common than today. Nixie tubes require a high voltage supply around +170 volts with a current of around 5 milliamperes (both vary with the type of tube). The high voltage ionizes the gas to give off light and the color is determined by the gas. Nixie tubes are available in different colors but colors that deviate from orange or orange/red are rare and generally associated with indicator or symbol tubes.

Acquiring the Tubes

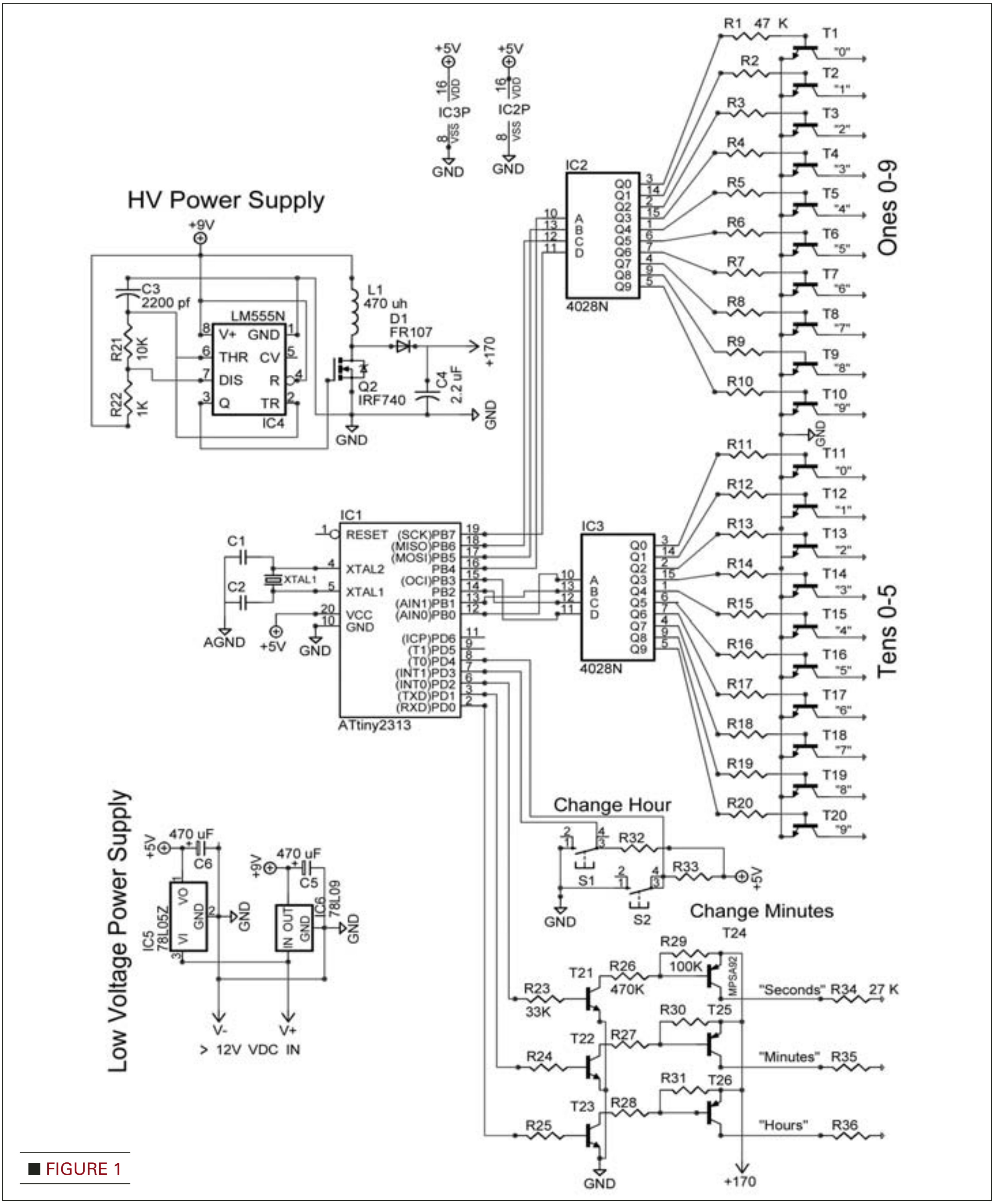
Nixie tubes have not been produced in the west since the '70s and production (as far as I can tell) of Soviet Nixie tubes stopped with the fall of the Soviet Union in the '90s (Soviet tubes always have a factory number and date of manufacturing on the tube).

Tubes can be purchased through websites and through auction sites. Auction sites will always be cheaper, but the quantity offered is usually higher. For example, the first Nixie clock I made used tubes I bought from a website for $10 a tube. A year later, I bought the same tubes in quantity for around half that. That's the price you pay for convenience and the assurance that all the tubes will work.

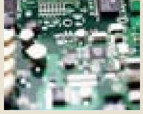
What Choices I Made for My Nixie Clock

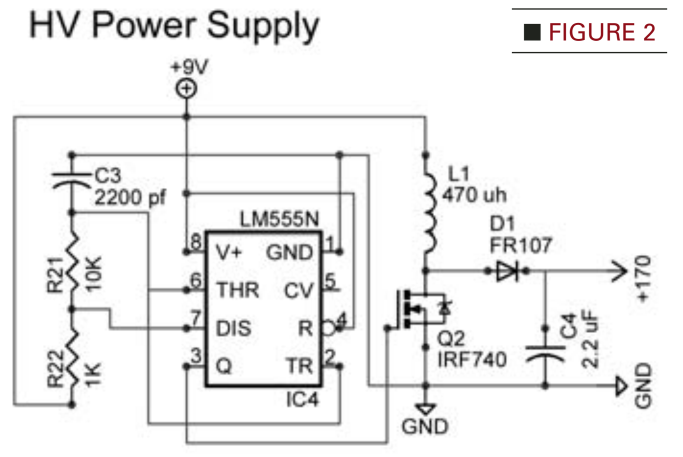
I'd like to thank everyone for their help and circuit fragments, which I have integrated into this version.

The Nixie clock discussed here

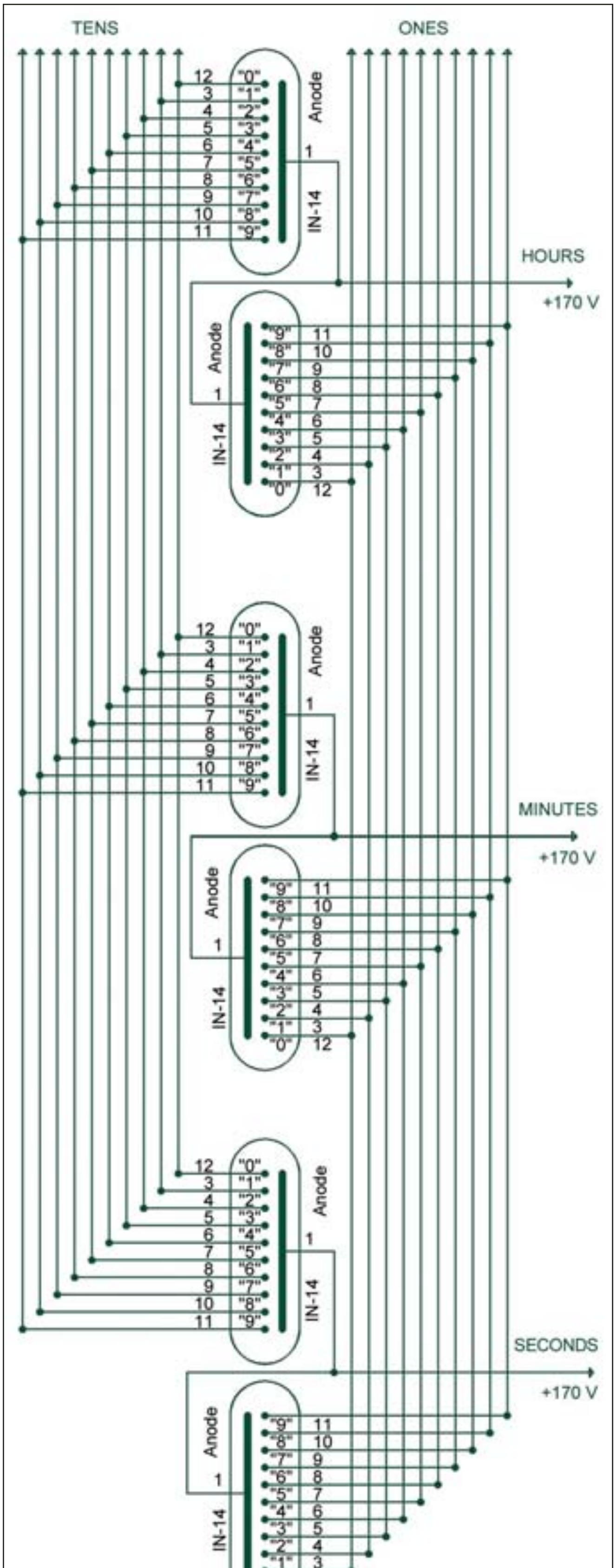

HV Power Supply
Low Voltage Power Supply
Ones 0-9
Tens 0-5
Change Hour
Change Minutes
ATtiny2313
LM555N
4028N
IRF740
78L05Z
78L09
MPSA92
"Seconds"
"Minutes"
"Hours"
> 12V VDC IN

■ FIGURE 1





■ FIGURE 2



■ FIGURE 3

— like any project — is the result of a series of choices. I wanted to make a Nixie clock out of readily-available components and, in fact, all the components — except for the Nixies — are available from Digi-Key. The CPU is an Atmel ATtiny2313. I chose it because it is a reasonably-priced, full-featured RISC chip with just the right amount of memory (2K) and ports to allow for the clock itself and expansion for additional options.

The high voltage display chip is a different matter. In the early '70s, a TTL chip was developed specifically to drive the Nixie tube — the 7441 and the 74141. At the same time, the Russian equivalent — the KM1551 — was released. These chips are still available on eBay and I use them when making special request clocks. However, they can be expensive in small quantities and the supply is limited.

For this clock, I drive the Nixies using a combination of two 4028 BCD to decimal decoders and 20 high voltage transistors to make the equivalent of two 7441s. The component count has gone up, but the parts are readily available. There are also freeware or free versions of tools for writing the code in a variety of languages.

I have chosen to use Bascom basic to program the chip. Basic is simple and easy to understand. Bascom is available as a download and can be used to program up to 2K of program space. To load the compiled program into the 2313, there is a wide variety of devices available (some of which are homemade). If you want to save yourself some time, you can purchase the chip, with the compiled program built in, parts, Nixies, and PCBs from me.

How the Hardware and Software Work Together

The overall view of the circuit is provided in Figure 1.

A DC supply is used to power the clock and no high or line voltages are required. There are two voltage regulators. One supplies five volts for the CMOS and CPU. The second is a nine-volt regulator to supply the high voltage power supply. The high voltage power supply (Figure 2) uses a

555 and a simple FET/inductor to produce an unregulated high voltage supply. As configured in the diagram and under load, it produces about 170V at 90 milliamps of current.

The heart of the clock is the CPU, in this case, an ATtiny2313. The crystal runs at 4.096 MHz. The ATtiny also has what are called “fuses,” which have to be set in order for the CPU to properly count and run the clock. By default, the fuses are set as:

- Brown Out Detection Disabled
- Divide Clock by Eight Internally
- Internal RC Oscillator 8 MHz

Since we are using an external crystal, we have to change the fuses to:

- Brown Out Detection Disabled
- External Crystal Oscillator 3.0–8.0 MHz

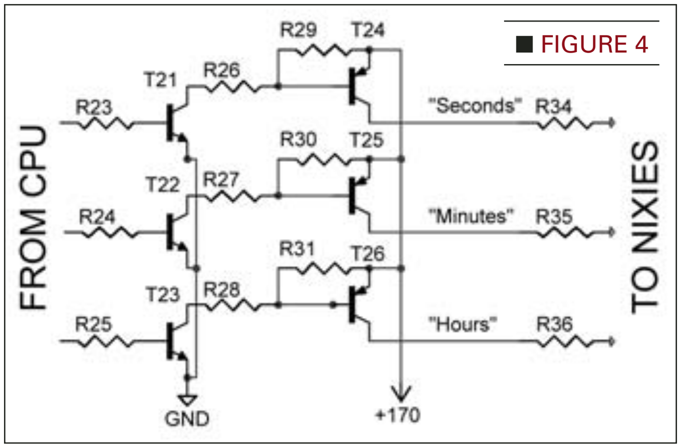
And unset Divide Clock by Eight Internally.

The software (see Listing 1 on the *Nuts & Volts* website at **www.nutsvolts.com**) sets up timer0 as a counter and then sets it to generate an interrupt every 65536 cycles. The interrupt can be a different value by changing the Prescale value. Prescale, in this case, is set to 256, so an interrupt signal is generated every 256 * 256 cycles or 65536 cycles. An interrupt has priority over everything, so once the timer overflows, an interrupt is generated and off we go to counting and display.

Since the crystal runs at 4.096 MHz, there are 62.5 interrupts every second (4,096,000/65536). This is not a “good” number to deal with since it is fractional. To make it an integer, we double it and make sure that two seconds equals exactly 125 interrupts or one second of 62 and one second of 63 interrupts. The seconds are then counted, 60 being equal to one minute, 60 minutes equal to one hour, etc. Two buttons are used to change the time — one to set the hours and one to set minutes. The software loops and continually tests the state of the pins to see if the buttons are pressed. If the buttons are pressed, the appropriate subroutine is called that increments the minutes or the hours by one.

Every interrupt calls a display subroutine called “multiplex.” The display routine is therefore called 62.5 times per second, resulting in a relatively smooth display. On the hardware side, I have used a simple scheme to illuminate the digits of the Nixies. They are switched on and off using a combination of two CMOS 4028’s BCD to decimal decoder chips and 20 MPSA42 high voltage switching transistors. Two digits are turned on at once so that a full number is displayed. Each 4028 is connected to four bits on portb for a total of eight bits or one byte.

Before the time can be displayed by the multiplex routine, the numbers have to be converted to their BCD values. Why? The CPU only understands binary, but our tubes are decimal. The number 15 in decimal has a 1 and then a 5 which means that two tubes must be lit, but 15 in binary (the number that the CPU understands) is 00001111, which means that 0000



■ FIGURE 4

PARTS LIST

PART	DIGI-KEY PART NO.	QTY
❑ ATTiny2313	ATTINY2313-20PU-ND	1
❑ 78L09	MC7809CTOS-ND	1
❑ 78L05	LM7805CT-ND	1
❑ FR107	FR107DICT-ND	1
❑ CD4028	296-2045-5-ND	2
❑ LM555	296-1411-5-ND	1
❑ IRF740	497-2931-5-ND	1
❑ MPSA42	MPSA42RLRAOSCT-ND	23
❑ MPSA92	MPSA92RLRAOSCT-ND	3
❑ 4.096 MHz Crystal	X082-ND	1
❑ 470 µH	M8636-ND	1
❑ Switch		2
❑ 1K	1KH-ND	1
❑ 10K	10KH-ND	1
❑ 27K	27KH-ND	3
❑ 33K	33KH-ND	3
❑ 47K	47KH-ND	20
❑ 470K	470KH-ND	3
❑ 100K	100KH-ND	3
❑ 22 pf	1429PH-ND	2
❑ 2,200 pf	1458PH-ND	1
❑ 2.2 µF 400V	493-1229-ND	1
❑ 470 µF 16V	565-1418-ND	2

WHAT I OFFER

■ My website is **www.glowingtech.com**. Full Nixie clocks, Nixies, and cases are available. A package of all parts, PCBs for the CPU and display boards, and six Nixies (IN-14’s or IN8-2, subject to availability) is offered at 109.95. A package of all parts and CPU PCB is 69.95. A package of all the parts but no PCB costs 59.95. A PCB for the CPU is 19.95. An ATtiny2313 with the compiled program is 14.95.

Shipping and handling is extra. Canadian residents pay GST. Ontario residents pay GST and PST.

Individual parts are also available.

■ FIGURE 5

would show up on half the output port and the other half would send 1111 to the poor 4028 which would display incorrectly. After running 15 through the BCD converter, the port would look like this: 0001 0101. The top four bits would be interpreted as a 1 and the bottom four as a 5, thus displaying correctly.

The hardware part of the display could be simplified. A 7441, 74141, or a Russian KM1551 chip would do the same job with a corresponding smaller parts count, but Digi-Key does not stock these parts, and the supply of these chips is limited. Once the number is converted and shows up on portb, the tubes are switched on and off in groups of two (Figure 3) using a combination of two high voltage transistors (MPSA92 and a MPSA42) shown in Figure 4.

Cases for the Project

The case for the clock can take many forms. Figure 5 shows some of the cases I have made. The housing has to take into account the size and shape of the Nixie tubes and the circuit boards. The case should highlight the tubes, since they are the center of the show. In my clocks, there are two separate boards: one for the CPU and circuitry, and one just for the display. That way, I tailor the display board to the type of tube I am using. I have a large number of printed circuit board designs for all the most common and some of the more uncommon Nixies. It gives me flexibility when designing the case. I always include a plastic cover over the tubes, as they are quite vulnerable to breakage.

Changes/Additions That Can be Made to the Clock

The clock uses 20 transistors to illuminate the two digits. A clock only really needs 16 for a full display (0 to 5 for the tens digit and 0 to 9 for the ones digit). I have included the full 20 transistors so that the clock can also be a counter.

The clock is inefficiently programmed. Assembler or C would

Useful Websites

■ **www.atmel.com** — Home of the ATtiny2313 and many useful development tools.

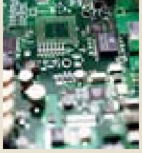
■ **www.mcselec.com** — Home of Bascom — a Basic compiler for 8051 and AVR chips.

■ **http://groups.yahoo.com/group/NEONIXIE-L** — NEONIXIE-L is a Yahoo! group for Nixie fans.

■ **www.cadsoft.de** — Eaglecad — Great CAD program for small projects.

result in a smaller program that could be used to do more. For instance, since we are using a high voltage for the clock, it would not be difficult to get it to count from a Geiger tube (the Geiger tube being the Nixies' spiritual cousin). You could watch the time AND know the local radiation level.

There are many humidity/temperature sensors that could also be integrated into the clock. Buzzers or other new functions could be defined. Friends have suggested that the clock could be hooked to a computer to display up-to-date stock prices. There are new Atmel RF RISC chips, so you could send the data to it wirelessly. If it can be counted, it can be displayed and look great in the process. **NV**



The frequency of the power coming into your house is 60 Hz, right?

(At least it is in the US) Everybody knows that, right? On a mailing list that I read regularly, there was recently a long, heated discussion about frequency stability of the AC power that's in our houses.

■ The AC monitor.

Resources

■ More information on the NIST Internet Time service can be found at **http://tf.nist.gov/service/its.htm**.

■ PC boards and the firmware for the AC Monitor are available from the SpareTime Gizmos web page at **www.SpareTimeGizmos.com**.

■ If you build the monitor and gather some interesting data — especially if you live somewhere other than the US — please join us on the Yahoo! SpareTime Gizmos group at **http://groups.yahoo.com/group/SpareTimeGizmos/** and let us know what you find!

Suppliers

■ Digi-Key: **www.digikey.com**
■ Arrow: **www.arrownac.com/**
■ Dallas Semiconductor: **www.maxim-ic.com/**
■ Mode Electronics: **www.mode-elec.com**
■ SpareTime Gizmos: **www.SpareTimeGizmos.com**

POWER LINE FREQUENCY MONITOR

I decided to find out for myself and built this dedicated monitor that displays the current line frequency with a 0.01 Hz resolution. The display itself is fun to watch, just to see how much something that we think is constant actually wanders around during the day. The monitor also logs the readings to a RS-232 serial port so you can capture the data over days, weeks, and months.

A Timely Application

The frequency of the AC power line has been used as the time base for clocks for many, many decades. This practice dates back long before the days of digital clocks and even before the age of electronics. After all, an old fashioned electric clock is nothing more than an AC synchronous motor driving a gear box that moves the hands. The RPM of a synchronous motor is strictly determined by the frequency of the power, and the gearbox is simply a mechanical divider. I thought it would be a good "time" to try this method again.

Hardware

The hardware for this project really couldn't be simpler. U1 is an Atmel ATmega8 AVR microprocessor that does all the work. DS1-4 are just four multiplexed seven segment LED displays. The AVR microprocessor can source enough current to drive the LED segments directly, but transistors Q1-4 are needed to sink the cathode current (which is the total of the individual segment currents) for each digit.

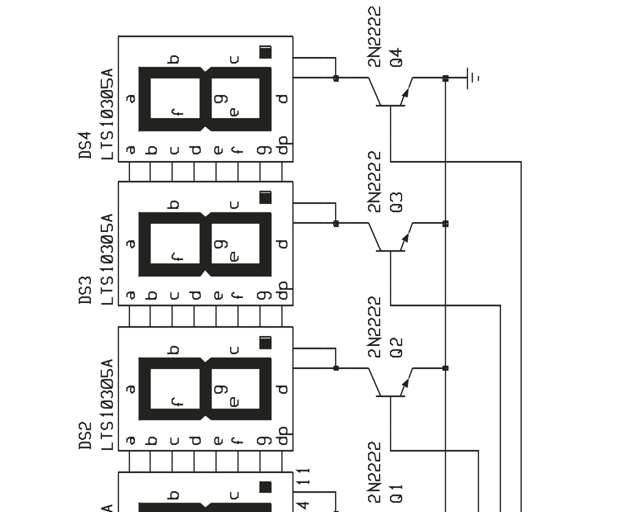
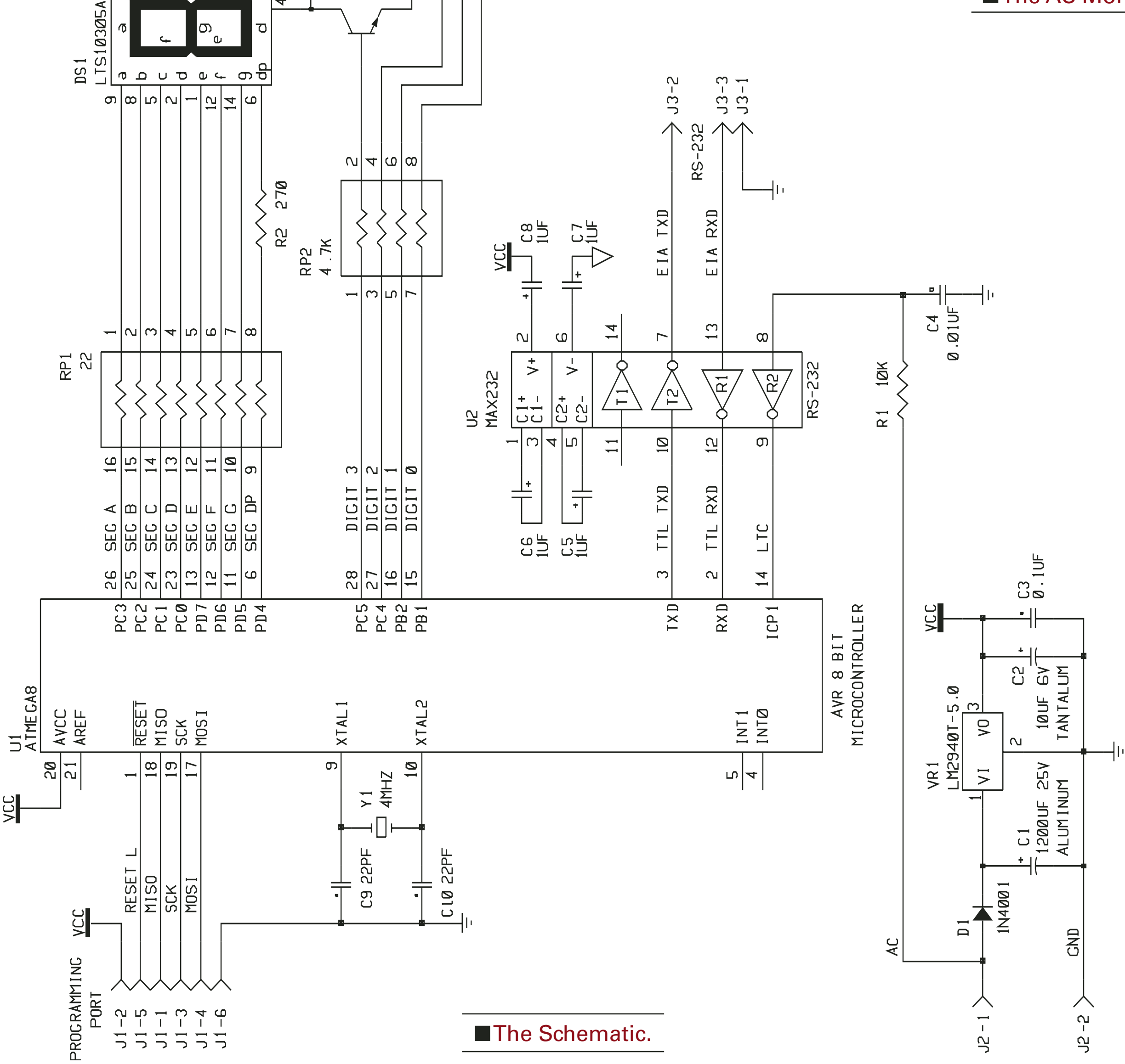
J1 is the programming port for the AVR microprocessor, and J3 is the serial port. U2 provides standard RS-232 levels for the serial port and, if you look closely, you'll notice that an otherwise unused RS-232 receiver in U2 is put to work to send a sample of the AC power to the microprocessor. This clever idea gives us noise rejection, hysteresis, and TTL level translation, all for "free." I wish I could take credit for thinking of it, but I first saw it in a *Circuit Cellar* article written long, long ago by Steven Reyer. D1, VR1, and C1-3 make a simple 5V regulated power supply that works from a 9V to 12V AC input. Note that you need to use an external transformer (the classic "wall wart") with this device — *it's not intended to connect directly to the power line!* And, of course, the wall wart *must have an AC output*; in this case, you can't use one with a DC output.

Accuracy

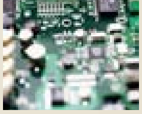
We need to spend a few minutes thinking about whether any changes we see on the display really reflect changes in the power line frequency, or whether they're just caused by errors and instability in our measuring instrument. Remember that the smallest frequency change we can display is 0.01 Hz

BY BOB ARMSTRONG

■The AC Monitor.

■The Schematic.



— that's one part in 6,000 at 60 Hz, or about 167 parts per million. Even an average microprocessor crystal like Y1 has an accuracy of 100 PPM or better, and that's a total for the calibration error, temperature drift, and long-term aging of the crystal. That means that any errors in our crystal time base are too small to see on the display. The crystal is only used for making the short term frequency measurements.

Construction

Because of the relatively few parts and the non-critical layout, construction is a breeze. I built the first prototype on a piece of perf board in a couple of hours, but you can order a printed circuit board (PCB) from my website at **www.SpareTimeGizmos.com**. The PCB makes assembly a snap and pretty much eliminates the possibility of wiring errors. If you do use the PCB, then pay careful attention to the silk screen which is printed on both sides of the board. Several components — including J1, J2, J3, VR1, and C1 — are mounted on the reverse (solder) side of the PCB. Nothing that would be taller than the displays is mounted on the front side, and the silk screen is your guide. Here are a couple of other tips to help you along:

- VR1 does not dissipate much power with normal input voltages and should not require a heatsink.
- The entire project fits nicely in a Hammond 546-1591DT plastic enclosure and the "Infrared" version of this box is the perfect color for red LED displays.
- The holes in the corners of the PCB are designed to accept #4-40 solder type swage standoffs, such as Mouser P/N 534-1653-2.
- Remember that you must use a wall wart with a 9V to 12V AC output!

PARTS LIST

LOC	SUPPLIER/PART NO.	DESCRIPTION
Resistors		
Unless noted, all resistors are 1/8W 5% carbon composition.		
❑ R1		10K
❑ R2		270 ohm
❑ RP1		16 pin 8 x 22 ohm DIP resistor
❑ RP2		Eight pin 4 x 4.7K SIP resistor
Capacitors		
❑ C1	Digi-Key/P10280	1200 µF 25V aluminum electrolytic
❑ C2		10 µF 6V tantalum
❑ C3		0.1 µF ceramic mono
❑ C4		0.01 µF ceramic mono
❑ C5-8		1 µF 25V tantalum
❑ C9, C10		22 pF ceramic mono
Integrated Circuits		
❑ U1	Atmel/ATmega8-16PC Digi-Key/ATMEGA8-16PC	Eight bit microprocessor DIP28
❑ U2	Dallas/MAX232	RS232 level converter DIP16
❑ VR1	National/LM2940T-5.0 Digi-Key/LM2940T-5.0	5V regulator TO220
Semiconductors		
❑ D1	1N4001	50PIV 1A power diode
❑ Q1-4	2N2222	NPN transistor TO92
❑ DS1-4	LiteOn/LTS-10304E Arrow/LTS-10304E	1.0" seven segment LED display
Miscellaneous		
❑ Y1	Digi-Key/X405	4 MHz crystal 20 pf HC-49/US
❑ J1		Six pin 0.1" dual row header
❑ J2	Mode/37-6202-0	
❑ J3	Mode/37-6204-0	
	Spare Time Gizmos/ ACMON-1A	Printed circuit board
	Hammond/1591DTRD Mouser/546-1591DTRD	Red plastic enclosure
	Keystone/1560A Mouser/534-1560A	#4-40 swages, 0.125" x 0.250"
	Digi-Key/HS104-1	Heatsink for VR1 (Digi-Key HS104-1)
		#4-40 mounting hardware for VR1
		Machined pin DIP sockets for ICs

NOTE: *The parts R3, R4, LED1, LED2, JP1, and JP2 also appear in the silk screen of the PC board. These are not used in the current version and should be left unpopluated.*

The AVR microprocessor must be programmed before it will do anything, and it can be programmed either "in-system" or in a separate standalone programmer. In-system programming is very convenient, especially if you want to change and experiment with the firmware. For in-system programming, you'll need an AVR programmer — such as the AVRISP, AVRISPII, or STK500. The AVRISPII is available from Digi-Key (see the parts list) for approximately $30. There are also many plans on the Internet for AVR programmers that attach to the PC's serial or parallel port — just do a Google search and you'll find several.

You can download the firmware for this project from the Spare Time Gizmos' web page mentioned above, or from the *Nuts & Volts* website at **www.nutsvolts.com**. In addition to downloading the firmware, the AVR microprocessor contains many "fuses" (they're really programmable hardware options) that must be set correctly before the AC monitor will work. Be sure these fuses are selected when programming your AVR chip:

- Brown-out detection level at VCC=4.0V
- Ext. Crystal/Resonator High Freq.; Start-up time 16K CK + 64 ms

Checkout

Once you've assembled the monitor and programmed the microprocessor, plug it in and turn it on. The display will initially show "—" for about one second while the firmware initializes and does a simple diagnostic. After that, it should show the current power line frequency. The firmware automatically adapts to either 50 or 60 Hz nominal frequencies, and with a suitable AC wall wart, it can

be used in any country. If the display freezes in the "—" state, then the most likely problem is that you've used a wall wart with a DC output rather than AC. If that's not it, or if the display doesn't light up at all, then you have some hardware problem. Check the output of VR1 for the proper 5V supply and, if that's okay, use an oscilloscope to verify that the AVR oscillator is running. If both these things are okay, then you most likely have a problem with your display and/or the driver transistors.

Logging

You can use the monitor just like a simple line frequency display. This might be interesting, say, if you were using a portable generator and wanted to keep tabs on the output. The monitor is most interesting, however, if you connect the serial port to your PC and log the results. The data sent out the serial port is at 9600 bps, 8-N-1, and the firmware sends a report once every minute. Each report is a single line that looks something like this:

172,10320,10321,59.98,59.97,60.02

In this example record,
172 → is the sample number (it increments for every record).
10320 → is the elapsed time, in seconds, by the crystal time base.
10321 → is the elapsed time, in seconds, by the line time base.
59.98 → is the average AC frequency for the last minute.
59.97 → is the minimum AC frequency recorded.
60.02 → is the maximum AC frequency recorded.

The idea is to capture data on a PC to time stamp the records when they are received. If your PC's clock is more accurate than either the crystal or the power line, then over the course of a few weeks or months, you can easily determine how much the two sources drift.

How do you get a PC with a clock that's more accurate than anything else? Actually, it's pretty easy with the Network Time Protocol — or NTP. Linux and Windows XP both implement NTP (although Windows calls it "Internet Time") and in the US, you can use NTP to synchronize your PC's clock with those at National Institutes of Standards and Technology to an accuracy of about 1/100th of a second. Other countries have their own standards agencies and Internet time servers.

Another interesting experiment would be to use something like Excel to plot the current frequency over a several day period. In principle, the frequency of the power grid goes down as the total load on the grid goes up, and you'd expect to see gradual changes in the average frequency over each day. In the afternoon, when the power system load is the highest, you'd expect to see a minimum frequency. Then from 2 to 4 am, when the load is the least, you'd expect a maximum. **NV**

MICROCONTROLLER LCD INTERFACE, A ONE-CHIP SOLUTION

Small microcontrollers such as the BASIC Stamp have greatly simplified automation and electronics design, bringing many into a field once ventured by few. Many projects require interaction with the user, both for inputting data and to provide feedback and results.

A liquid crystal display (LCD) is often chosen for the user interface.

LCDs range in size and capability, from the typical wristwatch display, to medical EKG monitors and advanced aviation-cockpit displays. Character (non-graphical) LCDs can be easily incorporated within microcontroller designs, as seen in Figure 1. This article provides a low-cost, one-chip solution for interfacing a microcontroller to an LCD.

Character-mode LCDs typically found in small projects come in a range of sizes, including one, two, or four lines of text. The number of characters per line typically ranges from eight to 40, with 16 and 20 being commonly used. Most LCDs incorporate an HD44780-compatible controller as part of the LCD module. Interfacing to the LCD requires four data lines and three control signals. Power, ground, and contrast round out the connections to the LCD. Interfacing to a microcontroller is straightforward, but can both tie up many of the available I/O pins, and consume a significant portion of the available program memory.

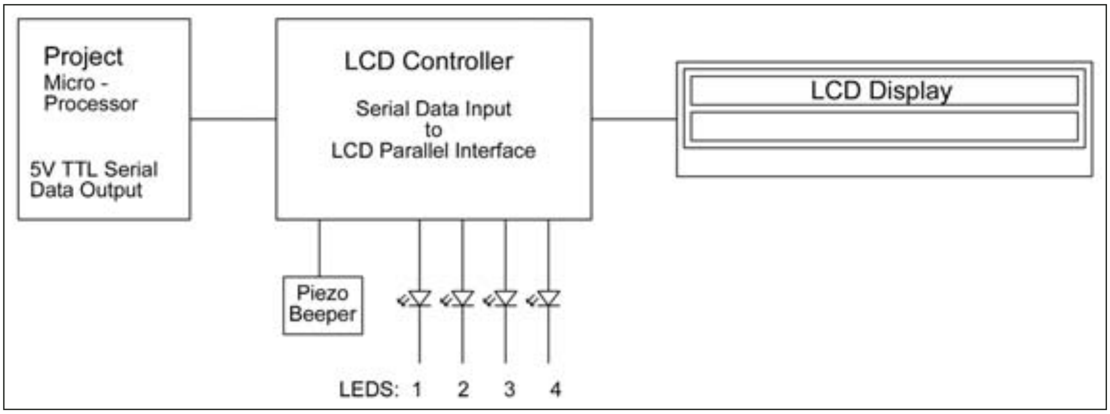
A good approach to alleviate these issues is to dedicate a microcontroller as an LCD driver. The main project's microcontroller can then dedicate a single I/O line for serial-data transmission to the LCD-driver microcontroller. The LCD driver then buffers the data and drives the LCD through its parallel interface. This concept is illustrated in Figure 2.

It is possible to purchase an LCD with a serial interface already incorporated into the LCD module. Unfortunately, one often pays a hefty premium for this convenience. By purchasing an LCD with a parallel interface, and adding one's own serial LCD driver, one can save money and incorporate any custom features desired.

The Nemesis is a Microchip PIC 16F88 available through Kronos Robotics. It is programmable in Athena, a PIC version of Basic. The language and development platform are available for download at no charge. The Nemesis includes an interrupt-driven hardware UART for serial communications. It has an 80-character buffer that virtually eliminates data-exchange synchronization and data-loss issues.

Figure 3 illustrates this microcontroller interfaced to a typical HD44780-compatible character

■ FIGURE 1. This photo illustrates an inexpensive two-line, character LCD displaying data from a microcontroller, (e.g., BASIC Stamp 1, BASIC Stamp 2, Nemesis, ZX-24, PIC, etc.).



■ FIGURE 2. An inexpensive, Basic-programmable PIC can be easily programmed to serve as a serial interface to drive LCDs.

LCD. The extra I/O pins on the Nemesis are put to good use, too. One pin selects the baud rate used to send serial data from the main project's microcontroller. If left unconnected, port 13 floats high, and the baud rate is 9600 (N81). If it is tied to ground, the baud rate is 2400 (N81). This slower baud rate was chosen since it is the fastest speed available on the BASIC Stamp 1.

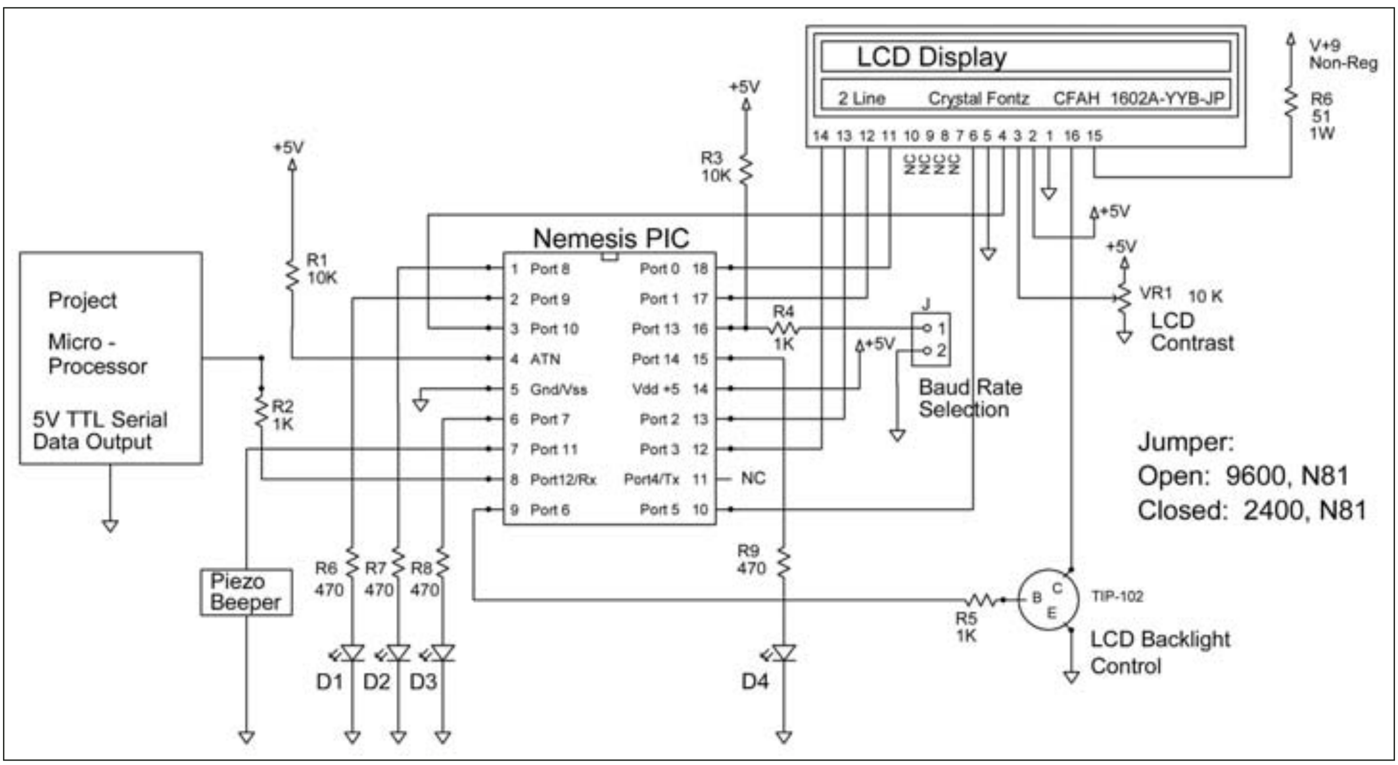
Ports 7, 8, 9, and 14 are used to drive LEDs. Although LCDs can convey much more information than an LED, they are often still useful as status indicators. A quick glance can convey power on/off, signal acquired, error mode, awaiting user input, etc. As software controlled digital output ports, they can be used for other purposes as well, such as driving a relay.

Port 11 is tied to a piezoelectric beeper to provide an audio alert to the user. Port 6 is driven by a hardware PWM (pulse width modulator). It is used to drive the LCD's backlight, giving one software control for On, Off, and Dim modes.

LCD Commands

In use, the main project's microcontroller sends serial data and commands to the LCD controller. The commands presently supported are shown in the LCD Driver Features sidebar. The Nemesis has spare memory available and is programmed in Basic. This makes it easy to add new commands or incorporate custom features as desired. For example, if higher speeds are required, the Nemesis supports baud rates of up to

■ FIGURE 3. The Nemesis configured as an LCD driver. A jumper is used to set the baud rate for the data sent from the main project's processor. Software control of the LCD's backlight, four LEDs, and a piezoelectric beeper is included.



LCD DRIVER FEATURES

Supported LCD Sizes
1 x 16, 2 x 8, 2 x 12, 2 x 16, 2 x 20, 4 x 16, 4 x 20

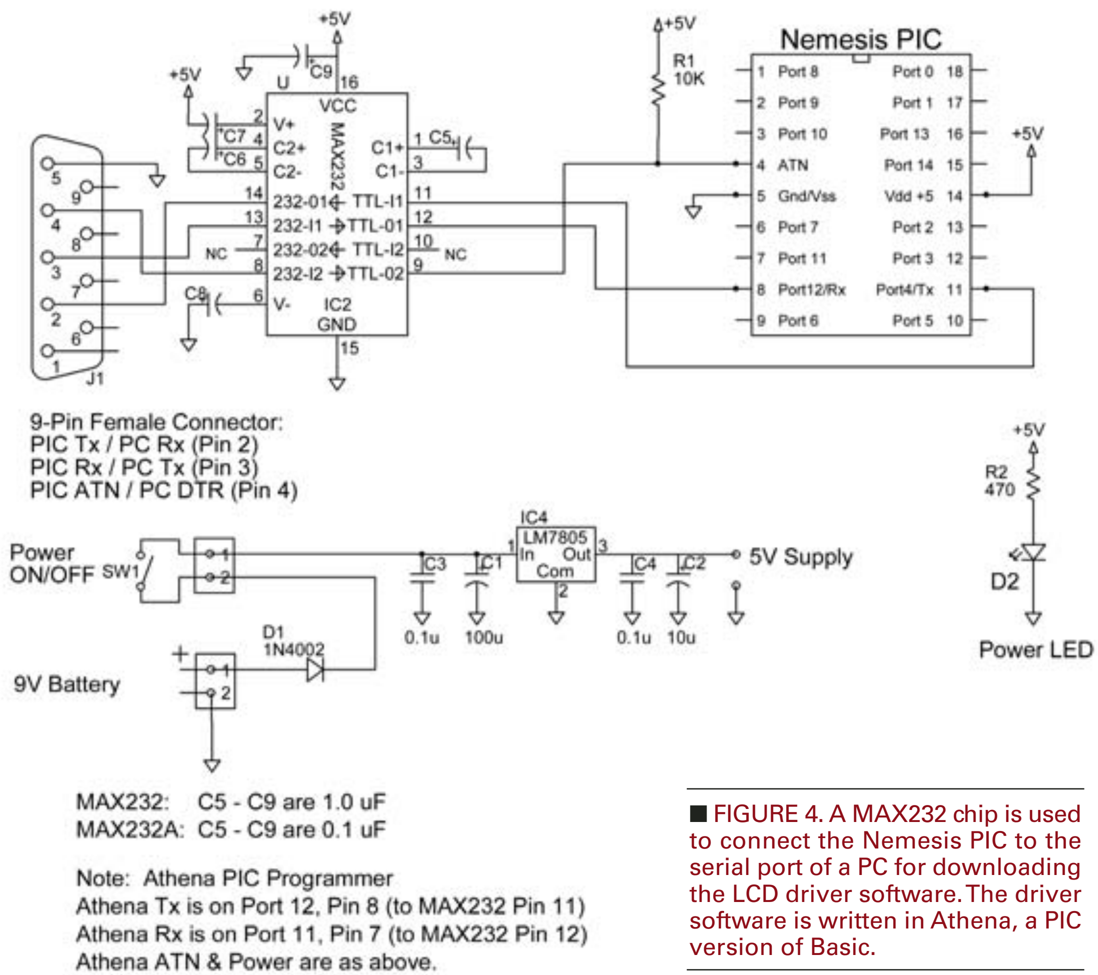
Commands	*Format*
Display ASCII Text	ASCII Chars
Clear Display	Esc C
Home Cursor	Esc H
Position Cursor	Esc P X Y (X=Line: 1-4, Y=Col: 0-40)
Beep	Esc Z
Display Byte	Esc X (X: 0-255)
Display Word	Esc X Y (X=High Byte, Y=Low Byte, 0 - 999d)
Send Control Code	Esc R X (X: 0 - 255)
LEDs	Esc L X Y (X=LED #1-4, Y: 1=On, 0=Off)
Cursor Mode	Esc V X (X: 1=Visible, 2=Invisible, 3=Blink)
Software Back Light	Esc J X (X: 1=On, 2=Dim 3=Off)
Configure Driver	Esc D X Y (X= # of Lines, 1-4; Y=Char/Line, 8-40)

NOTE: Commands begin with Esc (27 decimal, 1B hex), followed by a command character and any parameters. The command character is ASCII, (e.g., C = 67 decimal, 43 hex). The parameters are numeric (e.g., line numbers 1 through 4 are 1 decimal through 4 decimal). The following sequence sent to the driver will position the cursor on the top line (#1), fifth column (columns start at 0): 27, "P", 1, 4. This can also be sent as 27, 80, 1, 4 (all decimal), where "P" = 80 decimal.

19200. ASCII characters sent to the Nemesis are displayed sequentially from left to right across the current line, as one would expect. Commands are sent to the Nemesis by sending an escape character (27 decimal), followed by the command, and any parameters required.

To clear the display and position the cursor on the top line's leftmost character, one sends 27, "C" to the Nemesis. To position the cursor on the second line, fifth character position, one sends the following sequence: 27, "P", 2, 4. Lines are numbered 1 through 4, based on how many the actual display has. Character positions, however, are numbered 0, 1, 2, ... across the line. Given the ability to position the cursor wherever one desires, formatting one's output is trivial.

Displaying numeric data is also easy. Byte (0-255 hex) and "word" (90-0E7 hex [0-999 decimal]) commands are also included to convert the value from hex to an ASCII character string for display. Most of my projects use carefully formatted displays, positioning the data in desired locations. I have not included automatically wrapping text from the end of one line to the beginning of the next, since I have not required this feature. If one is using the display as a "terminal" displaying streaming data, one can easily incorporate formatting within the project's main processor's output routine, or modify the LCD driver's code.



■ FIGURE 4. A MAX232 chip is used to connect the Nemesis PIC to the serial port of a PC for downloading the LCD driver software. The driver software is written in Athena, a PIC version of Basic.

Hardware Setup

The Nemesis PIC microcontroller is a

general-purpose device. To be used as an LCD controller, it must first be programmed with the provided LCD controller software. Fortunately, this step is easy. Figure 4 illustrates the Nemesis connected to a MAX232 RS-232 serial communications chip. This chip converts TTL level signals, (0-5 volts), to an inverted, ±10 volt signal used to connect to a PC's serial port.

You can download the LCD driver program from the *Nuts & Volts* website (**www.nutsvolts.com**), and the Nemesis programming software from the Kronos Robotics website. Program the chip, and you are ready to use it as a display driver within your own project.

The LEDs, piezoelectric beeper, and backlight control are all options that are available for use, if desired. One can breadboard the Nemesis and the MAX232 serial communications chip to perform the programming, or purchase a socketed circuit board for the chip and a serial interface board from the Kronos website. Figure 4 illustrates the polarity of the 1 µF electrolytic capacitors connected to the MAX232 chip. If the MAX232A version of the chip is used, 0.1 µF capacitors are employed. These are non-polarized, and hence may be inserted in either orientation.

Power

No circuit board layout is provided for this project since, in use, the LCD driver is incorporated into your own main project. A word about power requirements is in order, however. The Nemesis requires a five-volt supply and draw less than 2 mA of current. The I/O pins can source up to 25 mA each for the LEDs, or other attached devices. If four LEDs are run at 15 mA each, plus a few mAs for the piezo buzzer, the chip could draw 70 mA. This exceeds the current that can be provided by the BASIC Stamp 1's on-board voltage regulator. An external power supply providing a regulated five volts is required. Without the LEDs, the

Sample Code to Display Information on an LCD

Data can be sent from a BASIC Stamp, ZBasic Chip, Nemesis, or PIC, etc. The baud rate is either 2400 or 9600, and is selected on the driver chip by tying Port 13 (Pin 16) to ground, or letting it float high, respectively. The data format is N81, no parity, eight data bits, one stop bit. The data is sent as a 5 V (TTL) signal, not as a bi-polar RS232 signal. If one wishes to send data to the LCD from a PC's serial port, a MAX232 type RS232 to TTL converter is required.

BASIC Stamp — I Example:

```
serout 0,T2400,("ABCDE")                 'Outputs text in quotes on pin 0
serout 0,T2400,(65)                      'Also outputs capital A, (65 dec)
serout 0,T2400,(27, "CHi There")         'Cls, then print Hi There
serout 0,T2400,(27, "P",2,0,"12345")     'Prints 12345 on Line 2, Column 0
```

BASIC Stamp — II Example:

Uses 9600 baud, N81, "non-inverted" by BASIC Stamp manual terminology.

```
serout 0,84,["ABC"]                  'Output a Text String in quotes
serout 0,84,[65, 66, 67]             'Output the same, ABC, sent as decimal data
serout 0,84,[27,"CHi There"]         'Cls, then print Hi There
serout 0,84,[27, "P", 1, 5, "*"]     'Now send Position Command to print an * on
                                     'Line 1 at the 6th Character position.
                                     '(Lines are 1, 2, 3, or 4)
                                     '(Columns are 0 - (N-1))
                                     '(27 decimal = Esc Char, used to send a Command)
```

Nemesis Example:

Uses a general I/O port pin, not the dedicated hardware USART port used for programming and debug.

```
const TxD 14                  'Use Port 14 to send the data to the LCD driver chip
const Esc 27                  'Decimal for Esc code, for commands
output TxD                    'Set this port in output mode
high TxD                      'Set port high before sending serout data
setbaud SBAUD9600             'Set serial IO to 9600,N81

serout TxD, "This is my Text"
serout TxD, Esc, "P", 1, 5, "*"        'Send Position Command to print an * on Line 1
                                       'at column 6.  (SeeBS-II, above)
serout TxD, 27, 80, 1, 5, "*"          'Same as above, sent as decimal data.
```

LCD DRIVER PARTS LIST

ITEM	DESCRIPTION
❑ Nemesis PIC	Kronos Robotics ($12.95)
❑ LCD	Two Line x 16 Characters Crystal Fontz CFAH 1602A-YYB-JP ($11.87)
RESISTORS	
❑ R1, R3	10 kΩ, 1/4 W, 5%
❑ R2, R4, R5	1 kΩ, 1.4 W, 5%
❑ R6, R7, R8, R9	470 Ω, 1/4 W, 5%
❑ R6	51 Ω, 1 W, 5%
❑ VR1	Potentiometer, 10 KΩ (LCD contrast control)
❑ T1	TIP-102 NPN Silicon Darlington Transistor
❑ PB	Piezoelectric Beeper (3-16 V) RadioShack RS-273-074
❑ D1-4	Red LEDs

Parts Suppliers

Nemesis PIC — Kronos Robotics (**www.kronosrobotics.com**)
LCDs — Crystalfontz (**www.crystalfontz.com**)

Other Components
Jameco Electronics — **www.jameco.com**
Mouser Electronics — **www.mouser.com**
Digi-Key Corp — **www.digikey.com**
Newark InOne — **www.newark.com**
All Electronics — **www.allelectronics.com**
Parallax Inc. — **www.parallax.com**
Microchip Technology, Inc. — **www.microchip.com**

on-board power supply can drive the chip and LCD without difficulty.

There are a number of different LCD backlight configurations. Crystalfontz has a broad selection of character-mode (and other) LCDs. The one illustrated in the schematic diagrams (Figures 3 and 4; the CFAH 1602A-YYB-JP), is a two-line, 16-characters-per-line, green/yellow display with an LED backlight that draws 130 mA, (240 mA max). The TIP-102 Darlington transistor is overkill for driving the backlight, since it can handle up to eight amps. It does not require a heatsink with the current levels used to drive the backlight. The value of the current limiting resistor, R6 (Figures 3 and 4), in series with the backlight depends upon the power supply voltage and the current drawn by the backlight.

Many of my microcontroller projects run from a 9V wall wart power supply. I draw the LCD's backlight power from the ~9-12 VDC, unregulated source. The 51 Ω, 1 W resistor then limits the backlight current to ~130 mA. This value can be decreased to draw more current and make the backlight even brighter, up to the display's maximum of 240 mA. The value of the resistor can also be decreased if the backlight is powered from the regulated 5 V supply. If this is done, however, the 5 V supply must provide the additional 130 mA. If a 7805, three-pin voltage regulator is used, it will require a heatsink.

A similar display is available with an edge-mounted LED backlight. It draws only 20 mA. Using this display would require a higher-valued resistor, to limit the backlight current. Clearly the "trivial task" of driving the LCD's backlight is non-trivial, and the designer has several decisions to make in this regard. Choose the backlight current-limiting resistor carefully, based upon the display's specifications, and the voltage of the power supply.

NEMESISPROGRAMMER PARTS LIST

ITEM	DESCRIPTION
❑ MAX232	TTL to RS232 serial communications chip
❑ LM7805	Three-pin voltage regulator, five volts
CAPACITORS	
❑ C1	100 µF, 35 V
❑ C2	10 µF, 10V
❑ C3, C4	0.1 µF, 35 V
❑ C5-9	1 µF, 20 V (with MAX232 chip)
❑ C5-9	0.1 µF, 20 V (with MAX232A chip)
RESISTORS	
❑ R1	10 KΩ, 1/4 W, 5%
❑ R2	470 Ω, 1/4 W, 5%
DIODES	
❑ D1	1N4002
LEDs	
❑ D2	Red LED (power indicator)
MISC.	
❑ SW1	SPSTtoggle switch (oower on/off)
❑ J1	Nine-pin, female RS-232 serial connector
❑ Batt	Nine-volt battery and connector

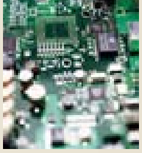
LCD Driver Software

As mentioned earlier, Athena Basic includes firmware to directly drive HD44780 parallel interfaced LCDs. The LCDinit command specifies the ports used for the data and control signals to the LCD module. LCDControl, LCDChar, and LCDWrite commands send control codes and ASCII data to the display. A simple data parser looks at the incoming data stream to determine if the next byte is a command instruction (Esc, 27 decimal) or simply more ASCII data to display. Commands such as clear screen, home, and position send control codes to the display. LED and piezoelectric-beeper commands are intercepted and the appropriate port set high, low, or pulsed for the beeper. In these instances, no data is sent on to the display itself.

The LCD Driver Features sidebar also illustrates the commands used by several common microcontrollers to display information on an LCD. Data is sent using the serial-output instructions, at either 2400 or 9600 baud, using the N81 format. The Nemesis doesn't require a crystal or ceramic resonator to control its internal clock frequency or communications baud rate. With an 80 byte buffer, the main project's processor can send data without regard to timing and processing delays. If the display is blank, be sure to adjust the contrast control!

Summary

By incorporating a serial-to-parallel LCD driver within one's project one can focus on the project's primary function, not on the nuances of LCD interfacing and control. Only a single I/O port is required for sending serial data to the controller, and programming memory is conserved for the main project at hand. Data display truly becomes trivial, and advanced user interfaces become readily achievable. Once again, microcontrollers make it easy! **NV**



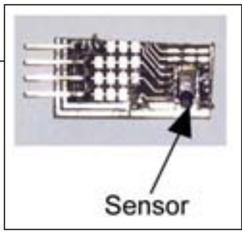
After building a temperature and humidity display — which confirmed my suspicions that my workroom really was making me hot (32° C) and bothered (85% H) — I decided that the answer was to control my environment.

Thus, the Climate Controller was born.

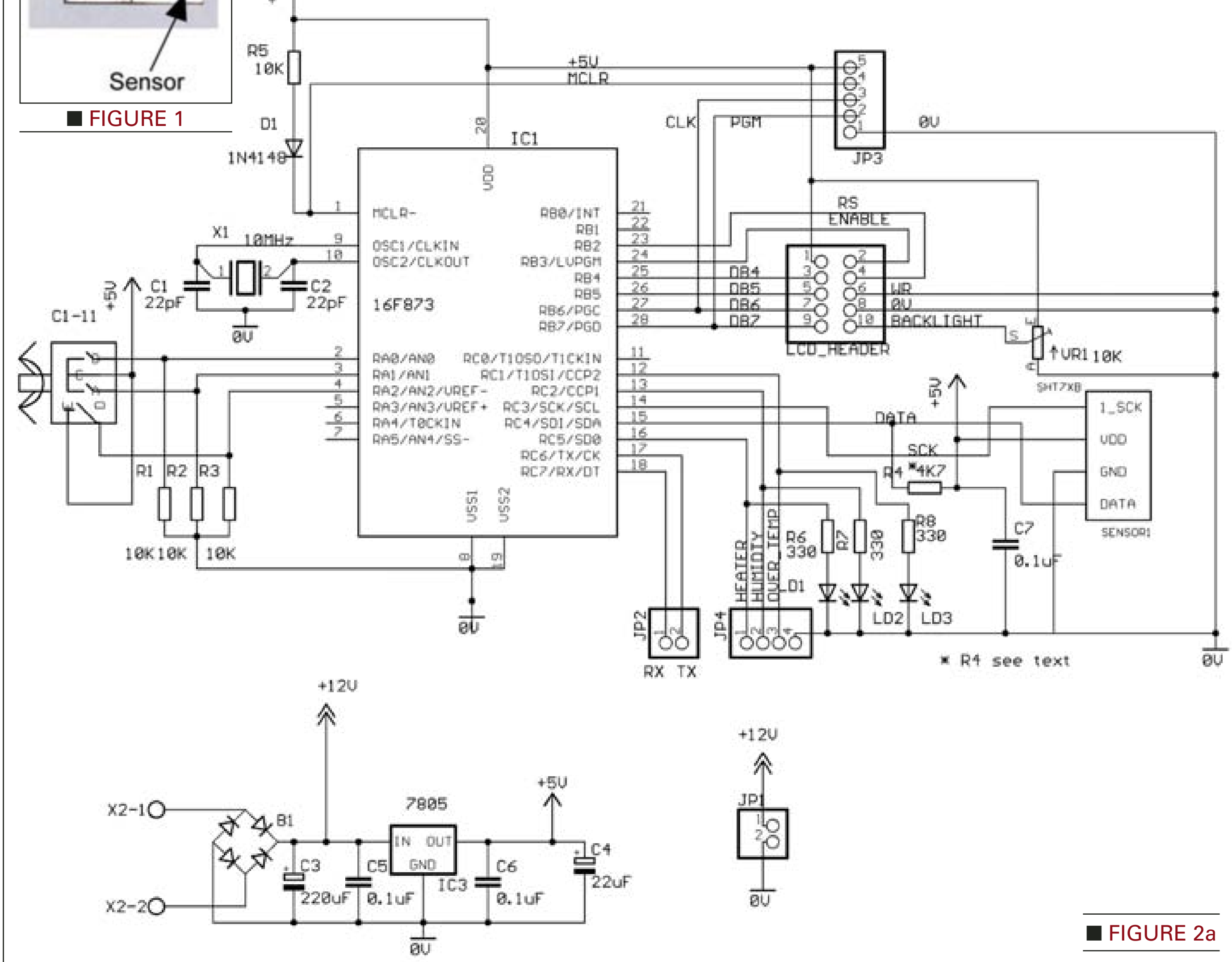
CLIMATE CONTROLLER

The Sensor

The Climate Controller uses the combined humidity and temperature sensor SHT11 from Sensirion. The SHT11 (Figure 1) is in a SMD package, while the SHT71 is a SIL four-pin version. The specifications for each are the same. The PCB has been designed to allow either to be used, or the more easily obtainable eight-pin DIP carrier version available from



■ FIGURE 1



■ FIGURE 2a

BY COLIN BARNARD

Parallax and Oatley Electronics.

The sensor contains a 14-bit analog-to-digital converter for temperature conversion, resulting in a maximum resolution of 0.1° C, spanning -40 to 123.8, while the humidity sensor uses a resolution of 12 bits (0.03% RH) with a range of 0 to 100% RH. Note that there is a maximum deviation of ±3% between 10-90% RH. Combine this with an integral serial synchronous interface and you have a highly accurate and easy-to-interface sensor.

The Controller

The controller is made up of three parts. First, the DC output board houses three switched MOSFET 10A outputs. Second, the AC control board gives you the option of housing the power transformer and one switched AC output. If the AC output is used, it takes the place of the heater DC output. Third, the controller board performs the switching, communicates with the sensor, updates the LCD display, and reads a rotary encoder for the trip settings. The controller board can be used as a stand-alone concept if you just require temperature and humidity readings. The same holds true for the two output boards; you only need to build the one that you will use.

Looking at the schematic for the controller (Figure 2a), we can see that it consists of no more than a Microchip PIC 16F873, a rotary encoder with integral pushbutton, and the SHT sensor.

The Sensirion sensor requires two pins from the PIC: one for bidirectional data and the other for the clock signal. If you use the Parallax part for this sensor, the pullup resistor R4 should be omitted, as this is already on the Parallax carrier board.

In parallel with the three trip outputs are indicator LEDs to show which output is active. The trip parameters are entered via the rotary encoder. I used this because it would be necessary to drill only one hole in a box and I liked the idea of "dialing" up the settings. The pushbutton is used to change between menus.

The mechanical rotary encoder is a two-bit incremental type and produces a binary Gray code output (see panel). The Piher C1-11 encoder has 30 pulses per revolution. As the software only needs to detect clockwise or anti-clockwise information, you can substitute almost any encoder you may have lying around. If you are lucky, that old discarded wheel mouse lying in the junk box may just use a rotary encoder (of course, you'll then need a separate pushbutton switch).

Although an encoder with a lower pulse/revolution can be used, don't be tempted to use one with higher pulses. You will need to experiment with the size of the knob or drive yourself mad trying to dial in the right data.

Connector JP3 is for in-circuit programming, D1 isolates the ~13 volt programming voltage from the five-volt circuitry during programming, and resistor R5 keeps the PIC out of reset during normal operation. If you wish to attach a reset button, then you can add one between D1 and ground. R1-3 are the pulldown resistors for the encoder, with the encoder pulling the PIC pins high as they are activated. JP1, the LCD header, connects to a standard LCD with VR1 as the backlight control. JP2 is brought out to a header and is spare. JP4 carries the switched output signals.

Heater is the under temperature switch, Humidity is for under humidity and OverTemp is, well, for over temperature. As this controller is not really a true closed loop type, you can control the window of temperature that is measured. The over temp trip can be no more than 10° above the under-trip temperature setting.

The power supply is standard with a 12 volt take-off point that could be used for the DC controller board. The input to the bridge rectifier can be either via a plug pack or the AC board.

Gray Code

■ Gray Code is a binary code that has built-in error checking. It achieves this by only allowing one bit position to change to zero at any one time. So, for example, the code 1111 + 1 = 1 is an illegal state as four-bit positions will roll over to zero.

The two-bit code as used by the Piher encoder is as follows:

00
01
11
10
00

AC Board

Figure 2b shows the AC schematic. This consists of a PCB mounted encapsulated transformer, a solid state relay for AC switching, a fuse, and some discrete components. What are the links for and why are two fuses shown? Starting at the primary side of the transformer, jumpers 1-4 allow for 120 or 230 volt mains input. If the transformer you use only has one primary winding, no links are required.

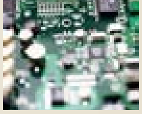
Although two fuses are shown, only one should be fitted. F1 is fitted if the switched output is to be driven directly from the non-isolated mains, such as a conventional heater or light bulb. The fuse is fitted in the F2 position if you prefer an isolated switched output using resistance wire or a low voltage heating pad. In the latter case,

Specifications

■ **Measurement and Display**
– Temperature: -40°C to 123°C (-40°F to -254°F)
– Scale selectable between Centigrade and Fahrenheit
– Humidity: 0% to 100% temperature compensated

■ **Outputs**
– Up to three DC switched outputs 10A or two DC outputs one AC switched output max 4A

■ **Uses**
– Greenhouse temperature/humidity control
– Small room temperature/humidity control
– Hatchling warmer
– Beef jerky drying



the transformer needs to have a secondary rating sufficient for the load.

The transformer specified has a 2.5 amp secondary at 12 volts. I recommend using a toroidal transformer. Apart from the fact that these tend to have higher amperage, they also provide better regulation and lower electrically-induced noise. Although not shown on the schematic, I recommend that a double pole, mains rated switch is connected between the mains inlet and transformer primary.

Link 5 connects one of the MT terminals of the SSR to either non isolated mains or the secondary of the transformer. The SSR MP240/120D4 contains a zero crossing circuit for minimum mains interference and a built-in snubber network for inductive loads and to prevent voltage spikes when the internal triac switches off.

JP5 is the low voltage input from the controller board and JP6 is the low voltage AC output that may be connected to the AC in of the controller board. R8 is the current limiting resistor for the internal LED of the SSR.

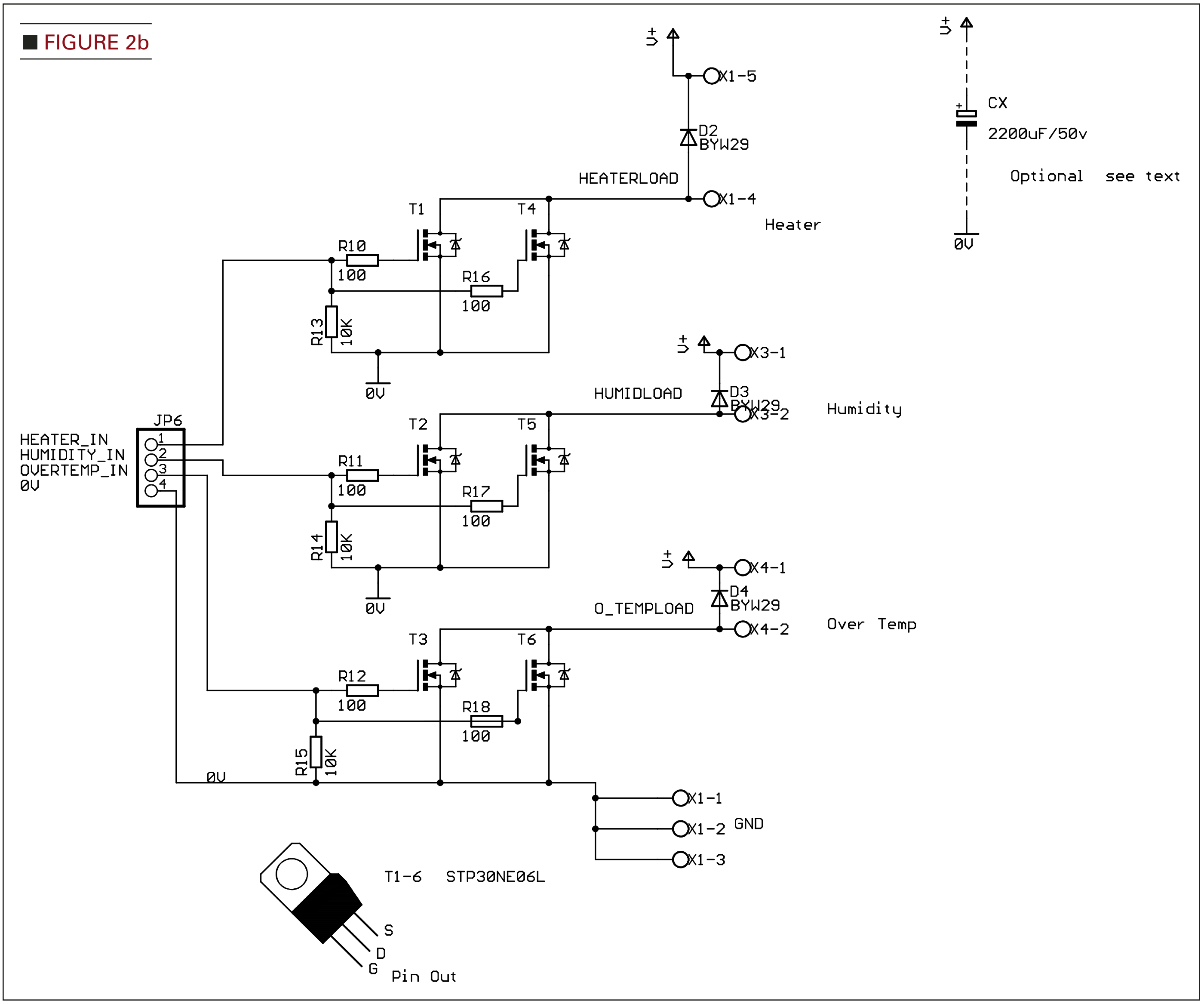
DC Board

Figure 2c shows the DC output circuit. T1(T4) and associated components are only fitted if you are not using the AC option for the heater control. Although all three MOSFET outputs look the same, there is a subtle difference in the way that the humidity and over temperature control act in respect to the heater output.

The heater control (if fitted) is a plain on/off switch. The other two outputs feature a "soft-start" control. They manage this by starting off as a pulse width output, with the duty cycle rising from 0 to 100% over a period of one second, and at switch off, performing in reverse.

I envisioned that the humidity control might be used to switch on a fan or water fountain to bring moisture back into the air when the air conditioning was in use. I found that an indoor ornamental fountain permanently switched

■ FIGURE 2b



on and a control switched fan took the dryness out of the air in a small room.

As a basic unit, only MOSFETs T1-3 need be fitted and, with the transistors specified, up to 10A can be switched. More than this would require T4-T6. The flyback diodes D5-6 are required if they are switching an inductive load. If using a resistive load — such as underground heating wire or similar — then the diodes are not absolutely necessary. The 100 ohm gate resistors are to help protect the PIC pins from excessive current and also help to minimize the heat dissipation that might occur while the MOSFET is switching.

The 10K resistors from gate to ground are to ensure that the MOSFETs stay off when the PIC is being powered up. The switched voltage can be up to 24 volt DC, and it is recommended that any motor-driven equipment is powered from a separate power source, with just the ground line common to both circuits.

To help prevent interference problems caused by a large current draw from a motor at rest, a provision has been made on the board for capacitor CX. This will definitely be required if using the controller supply to provide power to the motors. I also suggest that to minimize interference, fit 0.01 µF ceramic capacitors between each brush of the motor and the motor casing. The PWM frequency is 20 kHz and, with no shielding and without a toroidal transformer, the cables from the prototype were able to induce two very pretty vertical black lines moving horizontally across the picture of a television set 30' away in another room. This is only apparent if your local television station broadcasts in the VHF band, as most still do in Australia. The UHF band did not suffer from this problem, however, and good earthing and the use of a case and the specified transformer should reduce these effects. With loads up to 4.5 amps, the MOSFETs should not require heatsinks. The transistors specified have an RDS(on) of 45 mΩ. Any MOSFET with the same pinout and lower RDS(on) may be used, though it should be noted that the tracks of the PCB are only rated for approx 10 amps. (See the MOSFET table in the parts list for possible alternatives.)

Heatsink Thermal Ratings

Load Amps	4	10	15	20
°C/W	-	8	2.2	0.3
FETs fitted	1	1 or 2	2	2

*°C/W calculated max internal temp 100° C.

The °C/W ratings could be doubled if using the substitute MOSFETs listed.

Software

The software is written in C and assembler, and is fully commented for those wishing to tinker or recompile the source code (available online). Assembler is used for the functions that access the sensor. All of the functions take place within a 13.1 ms timing loop called TaskTime. This works by polling the Timer0 interrupt flag and returns control to the next function in line after the interrupt flag is set.

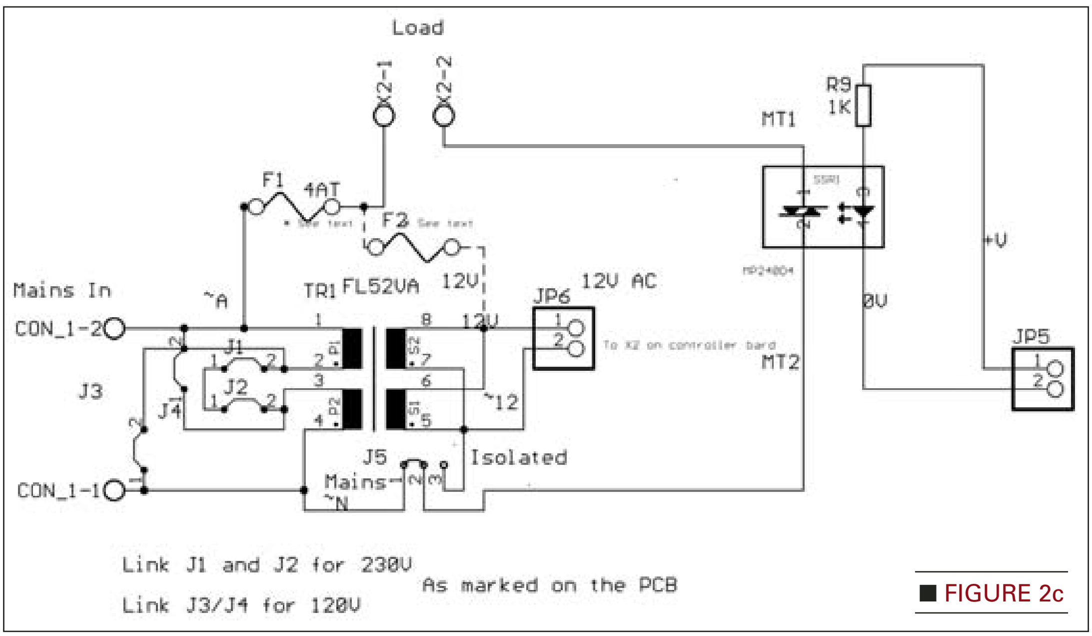
The SHT sensor requires a Reset sequence to wake it from sleep mode, and then requires a Transmission Start sequence before the measurement commands are sent. With this program, the only commands used are the Measure Temperature/Humidity control codes.

The sensor receives and transmits all data MSB first. The temperature and humidity are read alternatively every three seconds. After the read command has been sent, the controller has to wait for approximately 210 ms for the sensor to perform a 14-bit measurement.

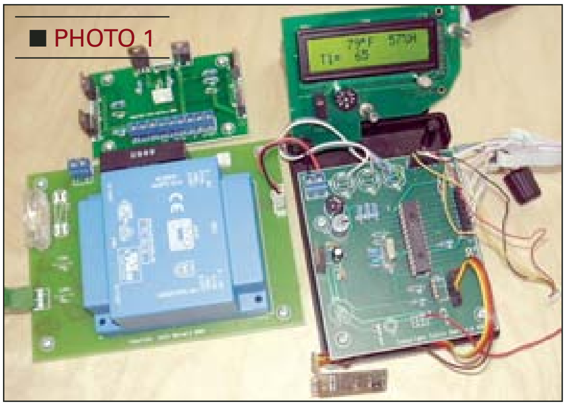
Because the software has been designed not to use floating point math and it was deemed unnecessary for this application to show fractional temperatures, some of the resolution has been lost in the rounding up to whole figures. The accuracy of the sensor has

SHT Commands

Code	Command	
0000x	Reserved	
00011	Measure Temperature	
00101	Measure Humidity	
00111	Status Register Read	not used
00110	Status Register Write	not used
11110	Soft Reset	not used



■ FIGURE 2c



■ PHOTO 1

not been impeded, however.

Safety

If using a heating element on either DC or AC, it is advisable to put a mechanical thermal fuse in series and touching the heating element in case of controller failure. Thermal fuses are available with various trip temperatures, and the one chosen should be just above the maximum temperature required. Thermal fuses come in two types: axial, in which the case is normally in contact with the supply; and radial, which tend to have isolated cases. They are very cheap and worth the investment.

As mentioned previously, the mains AC supply should be switched by a DPDT mains rated switch. Any mains filtering components and inline fuse should come after this switch, so that with the switch in the off position, you can safely change the mains input fuse. Some IEC mains sockets come with integral fuse compartments, mains switches, and mains filters. As the suggested transformer is an encapsulated type (Class II), an Earth connection is not required if using a plastic box for mounting.

If, on the other hand, you intend to build the supply and put it in a metal box or use a standard transformer, then the whole device becomes a Class I classified device and you will need a protective Earth connection. The transformer must be more than 6 mm away from the case sides, top, and PCBs, as must the distance between primary and secondary side components. The Earth wire point should be as close to either the mains cable entry or connector as possible. The interconnecting wire needs to be capable of carrying the rated current. In the case of the prototype, this was 6A wire.

The above points are in regard to European requirements and may differ in the US.

PARTS LIST

CONTROLLER BOARD

Resistors (1/4 W, 5%)
- ❑ R1-3, R5 — 10K
- ❑ R4 — 4.7K
- ❑ R6-8 — 330Ω
- ❑ VR1 — 10K

Semiconductors
- ❑ D1 — 1N4148
- ❑ B1 — Diode Bridge W04G
- ❑ IC1 — PIC16F873/10 MHz
- ❑ IC2 — SHT71/SHT11/SHTX - **[1] [2]**
- ❑ IC3 — 7805 500 mA, TO220 package
- ❑ LD1-3 — 5 mm LED
- ❑ X1 — 10 MHz crystal
- ❑ LCD — 2*16 with backlight - **[3]**

- ❑ ENC1 C1-11 with integral pushbutton - **[4]**

Capacitors (all except C3, 4, 2.5 mm pitch)
- ❑ C1-2 — 22 pF
- ❑ C3 — 220 µF/25V 8.5 mm pitch
- ❑ C4 — 22 µF/10V 5 mm pitch
- ❑ C5-7 — 0.1 µF

Miscellaneous
- ❑ DIP 28-pin IC socket (0.3" narrow or IC strip)
- ❑ DIP eight-pin IC socket (optional for sensor)
- ❑ SIP four-pin 1.27 mm (optional for SHT71 version)
- ❑ JP2,3,4 SIP pin headers
- ❑ LCD_HEADER 2 x 5 dual pin header
- ❑ X2 PCB mounting two-way block 5 mm pitch
- ❑ Enclosure to suit
- ❑ Hookup cable
- ❑ Standoffs 3 mm diameter qty 4
- ❑ Controller circuit board 2.7" x 3.9"

AC BOARD

Resistor
- ❑ R9 — 1K

Semiconductor
- ❑ SSR1 MP120D4(120V) / MP240D4(230V)

Miscellaneous
- ❑ TR1 FL52VA encapsulated 2*115V/2*12V@ 2.16A or equivalent
- ❑ F1 4A 20 x 5 mm antisurge *see text*
- ❑ PCB mounting 20 x 5 mm fuse holder or clips
- ❑ JP5, six two-pin header
- ❑ CON1, 2 PCB mounting two-way block 5 mm
- ❑ IEC Mains combined fuse socket (optional)
- ❑ DPST Mains rated switch (optional)
- ❑ Connecting wire 6A
- ❑ Standoffs 5 x 3 mm diameter qty 5
- ❑ AC circuit board 5.35" x 3.95"

DC BOARD

Resistors
- ❑ R10-12 (R16-18) — 100
- ❑ R13-15 — 10K

Semiconductors
- ❑ T1-3 (T4-6) STP30NE06L *see text*
- ❑ D2-4 BYW29

Miscellaneous
- ❑ JP6 SIP four-pin header
- ❑ PCB mount connectors to suit
- ❑ Connecting wire to suit
- ❑ Standoffs 3 mm diameter qty 4
- ❑ DC circuit board 2.05" x 3.05"
- ❑ Heatsinks (if needed for FETs)

SUGGESTED ALTERNATIVE MOSFETs

All Logic Level Types
- ❑ PHP45N03LT
- ❑ VNP35N07 protected OMNIFET™
- ❑ BUK102-50GL protected OMNIFET™
- ❑ BUZ100L
- ❑ IRL3303
- ❑ IRL2203N

SOURCES

■ [1] Sensor — **www.sensirion.com** also available from FarnellUK #3913065

■ [2] Parallax — **www.parallax.com** #28018 Newark — **www.newark.com** #07J2377

■ [3] LCD Display — Oatley Electronics — **www.oatleyelectronics.com** #DL6

■ [4] Encoder w/switch — **www.mouser.com**.

■ [5] Waterproof Heating Wire — Oatley Electronics — **www.oatleyelectronics.com** #099956 70 mΩ/meter #099957 20 mΩ/meter (waterproof) surplus price is $1.00/meter, with a 10 meter minimum order.

Construction

The Climate Controller is built over three boards, so you only have to construct the boards that you require.

*(Figures 3-5 are the PCB tracks and layouts used to construct this project and are available on the N&V website at **www.nutsvolts.com**)* Figure 3a shows the component layout of the controller PCB, with Figures 3b and 3c showing the top and bottom tracks, respectively. Figure 4a is the layout for the DC board, and Figures 4b and 4c are the PCB tracks. The heatsinks, if required, could form part of a U shaped case. The AC board is singlesided so that tracks carrying mains potential are away from inquisitive fingers! The component layout is Figure 5a and the PCB track side is Figure 5b.

Photo 1 shows the completed prototype. Note the DC PCB (top left) now has capacitor CX on board.

There is not much to the construction of the electronics. Start with the smaller components first, working up to the larger ones. With the AC board, note that there is a mounting pillar that is directly underneath the transformer that will need to be mounted before the transformer is soldered to the board.

The transformer has its own optional mounting holes. Don't forget to choose between 120 or 240 volts for the links at the transformer primary and the link for the SSR, if used. Once again, only mount the fuse F1 in the required position, depending on whether you are going to be switching non-isolated mains or from the secondary of the transformer.

The sensor needs to be mounted in a place that allows it to take accurate measurements of the area. If using the AC board, the sensor will need to be kept away from the heat caused by the power supply. Sensirion states that the wires to the sensor should be no more than 10 cm (4") long, otherwise signal loss may occur. This can be negated by routing the ground wire between the data and clock signal pins for longer runs. The EMC data sheet available for download from Sensirion also has a suggested low pass filter design for very long cable runs.

Before inserting the microcontroller and sensor, check the board for shorts and solder splashes. If everything seems to be in order, start checking the supply to the main board by first measuring the voltage at the output of the transformer (if used). If the off load voltage from the transformer is above 17 volts, you may wish to place an additional regulator circuit similar to the onboard one, but with a 12-volt regulator as an intermediate supply. This would reduce the voltage drop required by the five-volt regulator and you would not need to heatsink the regulator.

Up to 17 volts at the input of the five-volt regulator will result in it dissipating about 600 mw. If it is hot to the touch, a small slip-on heatsink will be required. Having made sure that five volts appear at pin 20 of IC1 and at VDD of the sensor, then switch off, insert the PIC, and attach the sensor. We are now ready to set up!

Setting Up

Once the unit has been housed and the sensor mounted in position, the unit can be switched on. Initially, the DC board should not be connected.

At switch on, the display should show a splash screen 'CLI-MATE 1' for three seconds and then the current temperature and humidity should be displayed. The temperature defaults to centigrade. If the display flashes "Error SHT," then the sensor has failed to be reset. Check all the connections to the sensor and make sure they are in the correct order. Next, check the pullup resistor (if fitted) and make sure that there is +5 volts on pin 15 of the PIC.

You need to power the unit down and power up again to clear the error message. If the error message still exists and you have a long cable to the sensor, try shortening it to around three inches. If this solves the prob-

Settings Menu

■ Long Push
#1 Scale Change C->F, F->C
#2 Humidity Trip set
#3 Under Temperature set
#4 Over Temperature set
#5 Return to #1

■ Short Push
#1 Returns screen to default at any time
#2 Displays Humidity setting
#3 Displays Under Temperature setting
#4 Displays Over Temperature setting
#5 No action

lem, then you will need to take note of the suggestions for long cable runs in the Sensirion EMC sheet.

The settings are accessed via the rotary encoder. The suggested encoder has an integral pushbutton, which accesses the four menu choices. The encoder is rotated CW to increment the settings and CCW to decrement the settings. The push-button function differentiates between short and long presses.

A long press is where the button is held down for approximately a half second or more. The long presses step through the menu selections. A short press at any time will revert the controller to run mode. Short presses will run through the trip settings without altering them. The default humidity trip setting is 50% and the temperature trips are set at zero. If you attempt to increase the humidity trip to more than 100%. the setting will roll back to 50%.

A similar result will happen with trip1 (under temperature) if you exceed 123° C or 253° F – it will roll over to 31° C (63° F). Trip2 (over temp) will not go beyond 10° more than the trip1 setting. The only way to override this 10° window is to set trip2 before setting trip1, although I can't think of a use for this feature.

When first setting up the unit, the decision will have been made whether to display the temperature in Centigrade or Fahrenheit. Therefore, while the real time temperature display will automatically convert between the two scales, the trip settings do not. If you decide to change the scale, the temperature trip settings will need to be altered.

What you connect the trip outputs to is left up to you! Bear in mind that there is no feedback control over motorized window openers or motorized valves, so if connected to such devices they must have their own fail safe or end stop/reverse circuitry. Underground heating wire with varying resistances/meter and with a waterproof coating are available from Oatley Electronics and other suppliers. **NV**

SPREADSHEETS

The Forgotten Analog Design Tool

by Thomas Henry

Nowadays, there's a ton of software kicking around to greatly simplify the design and construction of electronic circuits. Packages to capture schematics, perform simulations, lay out printed circuit boards, and so forth, abound. The trouble is, most non-professionals can't justify the typically stiff expense of these, especially when not used on a daily, income-producing basis. But there is one software tool that most everyone can afford (in fact, you probably already own it) and it really does speed up the creation of many new circuits: the spreadsheet.

Like Edgar Allan Poe's *The Purloined Letter*, the spreadsheet has been in full view for over 20 years now and yet has remained virtually invisible to the average electronics enthusiast. Far from being only a financial tool, it can easily be coerced into performing a number of useful, repetitive, and complex operations that really take the tedium out of customizing circuits.

In the June 2005 issue of *Nuts & Volts*, Peter Stark got the ball rolling by demonstrating how to apply spreadsheets to the digital world. The emphasis in this article is on analog design — an intimidating area to many since it often involves difficult or wearisome calculations. Not so anymore if you let the software help! You'll learn how to get started and master the general methods, and as a side benefit, create some handy reference sheets you can put to use right away.

As mentioned, you may already have a spreadsheet program on your personal computer. But if not, don't worry! The Resources sidebar shows several places on the Web where you can find inexpensive or even free spreadsheet programs. Most of these behave similarly, so the instructions given below (tested in Microsoft's Excel program) will work with little or no change regardless of the package. If this all sounds intriguing, let's dive in and see what's possible.

Suppose you need to amplify an audio signal by a certain fixed amount. The standard inverting op-amp configuration comes to mind, and indeed it's easy to compute the gain of such a circuit: just divide the feedback resistance by the input resistance. But in this situation, we need to work backwards. We already know the desired gain and wish to learn which pair of resistors will create it.

You could try a bunch of different values on your pocket calculator, recomputing the gain for each pair until you hit the magic number. But a slicker way is to simply let the spreadsheet program compute the ratio for *every* conceivable pair, and then read off the required combination. Best of all, if you print it out, you can punch it for a three-ring binder and have a ready reference for future work.

This is a simple example, but worth carrying out if for no other reason than that you can use it as a template for many different situations involving resistor pairs. Keep reading to learn how to implement it.

The Three Parts of an Electronics Sheet

To be most useful, an electronics spreadsheet should consist of three parts: a simple diagram or schematic showing to what situation the calculations apply, a brief verbal description of the circuit's purpose, and the calculation table. If you include these three parts in every spreadsheet you create, then not only will you avoid the old "hmmm ... I forget what this is supposed to do" syndrome later on, but you can share it with other users and get your point across precisely.

So, the first step is to draw a simple schematic. For convenience, this is placed in the upper left-hand corner of the sheet. It could be drafted using nothing more than Windows Paint (which comes along for free with that operating system), the line-art tools that are part of Microsoft Office, or even a stand-

FIGURE 1. By exploiting a spreadsheet program's built-in Copy/Paste operations, you can create this array of resistor values with very little typing. Bold print labels for easy human interpretation are placed alongside the actual values used for computation. The numbers should actually be entered sequentially, although they're shown split into thirds here to fit on the page.

10	10	**1K**	1000	**100K**	100000
11	11	**1.1K**	1100	**110K**	110000
12	12	**1.2K**	1200	**120K**	120000
13	13	**1.3K**	1300	**130K**	130000
15	15	**1.5K**	1500	**150K**	150000
16	16	**1.6K**	1600	**160K**	160000
18	18	**1.8K**	1800	**180K**	180000

FIGURE 2. A portion of a basic design sheet. The entire table spans all values of 5% resistors from 10 Ω on up to 10 MΩ.

Inverting Op-Amp Gain
This sheet shows the gain of an inverting op-amp for standard 5% valued resistors. Read the values of R1 down the left-hand column, and the values of R2 across the top row.

		10	**11**	**12**	**13**	**15**	**16**	**18**	**20**	**22**	**24**	**27**
		10	11	12	13	15	16	18	20	22	24	27
10	10	1.0000	1.1000	1.2000	1.3000	1.5000	1.6000	1.8000	2.0000	2.2000	2.4000	2.7000
11	11	0.9091	1.0000	1.0909	1.1818	1.3636	1.4545	1.6364	1.8182	2.0000	2.1818	2.4545
12	12	0.8333	0.9167	1.0000	1.0833	1.2500	1.3333	1.5000	1.6667	1.8333	2.0000	2.2500
13	13	0.7692	0.8462	0.9231	1.0000	1.1538	1.2308	1.3846	1.5385	1.6923	1.8462	2.0769
15	15	0.6667	0.7333	0.8000	0.8667	1.0000	1.0667	1.2000	1.3333	1.4667	1.6000	1.8000
16	16	0.6250	0.6875	0.7500	0.8125	0.9375	1.0000	1.1250	1.2500	1.3750	1.5000	1.6875

alone drafting package that has an export option. Most spreadsheet programs let you embed a graphic directly. For example, in Excel, you go to the menu bar and select **Insert>Picture>From File**. File types like .gif, .jpg, .bmp, etc., are handled with ease.

Okay, so you've got the diagram in place now. Next to this, write up a brief description of what the sheet does and how to interpret the results. As mentioned above, this not only serves as a memory jog later on, but also makes the sheet more useful to others. In Microsoft Excel you could put this in a text box by clicking on that icon (it looks like a sheet of paper with a capital letter A on it), or you could simply enter the description in an empty cell, letting it spill over as needed.

Setting Up a Resistor Template

Now it's time to work on the calculation table. For the inverting amplifier example, we'll need to fill out a row and a column with the standard 5% values for resistors. You might object, thinking this to be a tedious task, but two things help here. First, remember that you need only do this once and can then use the sheet as a template for other resistor calculations later on. Also, there are a number of software tricks to greatly reduce the amount of typing required. Just follow these steps and see how fast it can be:

1) Leave a couple blank rows at the top. Now starting at cell **B3**, enter the 23 standard 5% resistor values one after another down the column: 10, 11, 12, 13, 15, 16, 18, 20, 22, 24, 27, 30, 33, 36, 39, 47, 51, 56, 62, 68, 75, 82, and 91.

2) The following entries come in decades. That is, 10 becomes 100, 11 becomes 110, eventually moving into the thousands, the tens-of-thousands, and so on. To automate this, with the cursor in the empty cell immediately below the last number you punched in (91), enter a formula that will create a result 10 times the value of the number in the top cell of that column (10).

Most modern spreadsheets let you do this with a combination of keyboard and mouse point-and-clicks. For example (depending what row you started with), the formula in this cell might appear as **=B3*10**. That's what the formula looks like but, of course, it'll be evaluated and displayed as 100, the next entry in the resistor sequence.

3) Now simply replicate that cell over the remaining rows below. In Microsoft Excel, this is done by placing the cursor over the little square on the lower right-hand corner of the cell. The pointer will change to a cross. Now simply drag it down to

FIGURE 3. A slightly more complex design sheet. Again, only a portion is shown. Notice the parameter Vin, which appears in the upper left-hand corner of the table.

Voltage Divider
This sheet shows the outputs of a voltage divider for standard 5% valued resistors. Vin (currently set at 10V) can be changed to any desired input voltage and the sheet be recalculated. Read the values of R1 down the left-hand column, and the values of R2 across the top row.

Vin = 10		**10**	**11**	**12**	**13**	**15**	**16**	**18**	**20**	**22**	**24**	**27**
		10	11	12	13	15	16	18	20	22	24	27
10	10	5.0000	5.2381	5.4545	5.6522	6.0000	6.1538	6.4286	6.6667	6.8750	7.0588	7.2973
11	11	4.7619	5.0000	5.2174	5.4167	5.7692	5.9259	6.2069	6.4516	6.6667	6.8571	7.1053
12	12	4.5455	4.7826	5.0000	5.2000	5.5556	5.7143	6.0000	6.2500	6.4706	6.6667	6.9231
13	13	4.3478	4.5833	4.8000	5.0000	5.3571	5.5172	5.8065	6.0606	6.2857	6.4865	6.7500
15	15	4.0000	4.2308	4.4444	4.6429	5.0000	5.1613	5.4545	5.7143	5.9459	6.1538	6.4286
16	16	3.8462	4.0741	4.2857	4.4828	4.8387	5.0000	5.2941	5.5556	5.7895	6.0000	6.2791
18	18	3.5714	3.7931	4.0000	4.1935	4.5455	4.7059	5.0000	5.2632	5.5000	5.7143	6.0000

row 141 and release the mouse button. All of the remaining values are magically created, from 10 Ω to 10 MΩ!

The replication process has copied the formula to successive cells, but since a relative reference is assumed, it's revised to **=B3*10**, then to **=B4*10**, and so on. In some older spreadsheet programs, you may have to carry out this operation with a combination of copy and paste, but it's still faster than typing everything in by hand since you can do dozens of numbers at once. While this may read long, in practice, you can create all 139 values in a minute or two and with very little keyboard work. (Of course, if you're a zippy typist ...)

4) Format the column any way you'd like. You could make the entries display as ordinary fixed-point numbers with commas, or in scientific notation, or whatever. It's up to you, since the full precision values are maintained internally no matter how they appear on the screen.

So, you've got a column of standard values now, and these will refer to one of the resistors in our example. But with all those zeroes kicking around, it can be a little hard to read. So, in the first column (referenced as **A** on my system and deliberately left blank so far), type in the usual shorthand version for each number: 1K for 1,000, 330K for 330,000, and so on. These are just labels to make reading the table a little easier and don't affect the calculations in any manner.

FIGURE 4. Decibel tables are great for home study.

Decibel Tables
These tables show the decibel equivalents for various ratios of output to input voltages (voltage gain).

Vout/Vin	dB	Vout/Vin	dB	Vout/Vin	dB
1	0.0000	51	34.1514	1	0.0000
2	6.0206	52	34.3201	10	20.0000
3	9.5424	53	34.4855	100	40.0000
4	12.0412	54	34.6479	1000	60.0000
5	13.9794	55	34.8073	10000	80.0000
6	15.5630	56	34.9638	100000	100.0000
7	16.9020	57	35.1175	1000000	120.0000
8	18.0618	58	35.2686	10000000	140.0000
9	19.0849	59	35.4170	100000000	160.0000
10	20.0000	60	35.5630		
11	20.8279	61	35.7066		
12	21.5836	62	35.8478		

You might want to format these with bold print to make them stand out a bit (see Figure 1).

Now we need to create a row of resistor values along the top. You could perform steps similar to what we've just completed, but there's a faster way. Most spreadsheets have a variety of matrix operations built in, including one called Transpose. The purpose of this operation is to copy a row as a column and vice versa.

Consider the two columns so far as a matrix containing 139 rows and two columns. Invoke the Transpose function to create a new matrix from it containing two rows and 139 columns. In Excel, you can access this operation from the **Paste Special** menu. If the details hang you up somehow, be sure to check out the Help screens in your program.

Assuming everything's gone well, you'll rapidly end up with a copy of the first two columns, but arranged now as the top two rows. See Figure 2, and also notice how the schematic and text description referred to earlier appear at the top. Be sure to store your work in progress. You might also want to save this as a template, since it can be used for lots of different circuits involving two resistors.

A Multitude of Calculations

Now comes the fun part — seeing the calculations fall into place! Plop the cursor down in the first empty cell at the intersection of R1 = 10 ohms and R2 = 10 ohms). Then enter the formula to calculate the ratio of these two. It should look something like this: **=C$17/$B18** depending on which row and column you started with. With most spreadsheet programs, you can do a

FIGURE 5. Here's a portion of a design table that makes designing reactive circuits — like filters — a snap. Actually, the resistors shown here are way too small for a practical circuit, so you'd want to use values further along in the list. Just scroll the table until you locate some reasonable numbers.

Bandwidth Limiting in an Inverting Amplifier
This sheet shows the -3 dB points for bandwidth limiting (which works for both low pass and high pass) in an inverting amplifer, at various standard values of R and C.

		10 pF	22 pF	47 pF	100 pF	220 pF	470 pF	0.001 µF	0.0022 µF	0.0047 µF
		1.00E-11	2.20E-11	4.70E-11	1.00E-10	2.20E-10	4.70E-10	1.00E-09	2.20E-09	4.70E-09
10	10	1,591,549,431	723,431,560	338,627,538	159,154,943	72,343,156	33,862,754	15,915,494	7,234,316	3,386,275
11	11	1,446,863,119	657,665,054	307,843,217	144,686,312	65,766,505	30,784,322	14,468,631	6,576,651	3,078,432
12	12	1,326,291,192	602,859,633	282,189,615	132,629,119	60,285,963	28,218,962	13,262,912	6,028,596	2,821,896
13	13	1,224,268,793	556,485,815	260,482,722	122,426,879	55,648,582	26,048,272	12,242,688	5,564,858	2,604,827
15	15	1,061,032,954	482,287,706	225,751,692	106,103,295	48,228,771	22,575,169	10,610,330	4,822,877	2,257,517

combination of keystrokes and mouse drag-and-drops to quickly enter this formula.

Pay close attention to the dollar signs in this expression. Normally, a spreadsheet defaults to a relative reference scheme (as it did when we entered the resistor values earlier). But in this case, we need to specify an absolute row or column, and that's the purpose of the dollar sign flags. For example, **C$17** says to reference the value which *must* be in row 17. On my system, this will be an R2 value. Then we divide this by **$B18**, and this refers to a value which *must* lie in the **B** column. The **B** column contains the values of R1.

Finally, using drag-and-drop if your software permits it, or else a Copy/Paste operation, replicate this formula across the entire spreadsheet. Bang — in the blink of an eye, you'll have the gain of an inverting op-amp for every possible pair of standard 5% value resistors! You should end up with a sheet like the one in Figure 2.

A More Complex Example

The problem is a common one: what will the output of a voltage divider be for various resistor strings, and for different input voltages? Figure 3 shows a portion of the resulting sheet. In this case, the computation depends on three quantities: R1, R2, and the applied voltage Vin. To make the sheet truly general-purpose, place the value of Vin in its own cell and label it. Position it in the upper left-hand corner of the table, so that it's easy to spot.

Now, have any calculations refer to this parameter instead of using an embedded constant. On my system, a typical entry looks like **=B16*C$17/($B18+C$17)**. Again, watch the dollar signs. In this case, **B16** refers to the absolute location of column 16 and row **B**, which contains the input voltage. When the sheet is filled out, you'll see the output level for every combination of standard resistor values strung across 10 V.

If you need to do it again, for 15 V say, simply change that one single value in the upper left-hand corner and recalculate; the entire sheet is updated in a trice, and placing Vin in an easy-to-find locale makes it simple to experiment with many different voltages.

Much More Than DC Circuits

Creating spreadsheets for simple DC circuits is useful, and a great way to get started. But there are many other unusual applications just waiting to be discovered. How about making a sheet to calculate the decibel equivalents of voltage ratios? This is not only a handy reference to keep in your lab notebook, but also makes a great study aid should you wish to learn more about decibels and get an intuitive feel for what they mean. Figure 4 shows the layout.

To design this one, create a column of voltage ratios, starting at one and going as high as you want. For larger ratios, set out a second area where the jumps are bigger. Then simply copy in the standard formula **=20*LOG10(A11)**. In this case, all references are relative and merely refer to the adjacent number in the **A** column, so there are no dollar signs. And **LOG10** is nothing more than the base-10 logarithm function, part of every spreadsheet program's bag of tricks.

Bring on the Capacitors

Now let's up the ante a bit and see how to incorporate capacitance into our spreadsheet calculations. Here's a practical example. Good quality audio circuits typically employ bandwidth limiting. This is to ensure that frequencies below and above the audio spectrum are rejected. The result is a circuit free of subsonic rumble or supersonic interference.

Figure 5 shows straightforward — yet reliable — circuits to handle both the low pass and high pass operations. Notice that one formula applies to both circuits, so you get double the bang for your buck here. That is, if the combination of R and C gives a cutoff frequency of 1,000 Hz, then in the low pass circuit, frequencies above this value are attenuated, and in the high pass version, frequencies below it are rolled off.

For this spreadsheet, you'll need resistor values down the left-hand column, and capacitor values along the top row. The resistors we've already dealt with; you can simply use your template from before, keeping the column on the left but deleting the top row. Then punch in standard values for the capacitors. I used decade multiples of 2.2, 4.7, and 10, since these are the caps I usually have on hand. But feel free to employ any other intermediate ones you desire.

Since capacitance is typically quite small, there are lots of zeros and decimal places running around, which could make the table a bit hard on the eyes. So, as before, I created a row which gives the human equivalent as boldface labels (e.g., **100 pF**), and immediately below this is the actual number to be used in the calculations (e.g., 1.00E-10).

If you've got your resistor and capacitor values punched in, then save this as a template, too. It'll come in handy for all sorts of reactive circuits.

The formula you need for Figure 5 is **=1/(2*PI()*$B18*C$17)**. The numbers and letters may vary,

Resources

Here are several resources if you don't have a spreadsheet program on your computer — all three are fully-functional freeware!

• OpenOffice
www.openoffice.org

• Gnumeric
www.gnome.org/projects/gnumeric

• Sphygmic Software Spreadsheet
www.ds.unifi.it/~stefanin/AGR_2001/SH/sssheet.htm

depending on what row and column you use to start your sheet. As usual, watch out for the dollar signs, since we want to grab resistor values from the column only, and capacitor values from the row only.

Here's something new. The ubiquitous constant π (PI) shows up in the formula. Just about all spreadsheet programs have this built in, and by using it, you can get a good 15 decimal places of accuracy, much better than the lousy approximation 3.14 you used in junior high.

As an example of how quickly a problem can be dispatched with this sheet, imagine you wish to roll off the high end of an audio circuit at 100 kHz, say, to avoid spurious oscillations. Scrolling through the table you'll instantly locate values of 75 KΩ and 22 pF for R and C, respectively. These will give a -3 dB point of 96,458 Hz, which is close enough. And you can look for other suitable combinations if you wish to raise or lower the resistor value to change the overall gain of the circuit. It's a snap now!

And That's Just the Start

I'll confess that I only stumbled onto the notion of using spreadsheets for electronic design recently. But now I'm hooked — and I hope the examples presented in this article have piqued your interest and that you'll consider creating and sharing your own spreadsheets for electronic design. Judging by the popularity of the *Electronics Q & A* and *Tech Forum* columns, the readers of *Nuts & Volts* comprise an active, generous community. Just imagine what kind of database we could come up with if everyone contributed a design sheet or two ... **NV**

About the Author

Thomas Henry is the author of over 130 articles and six books on the subjects of electronic design, microcomputers, music synthesizers, astronomy, caves, and magic. He is a mathematics instructor at South Central College in North Mankato, MN.

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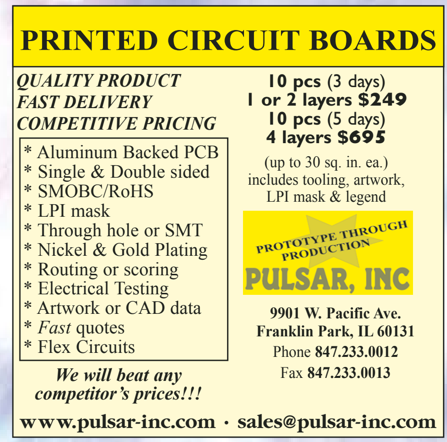

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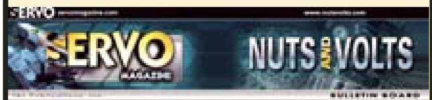

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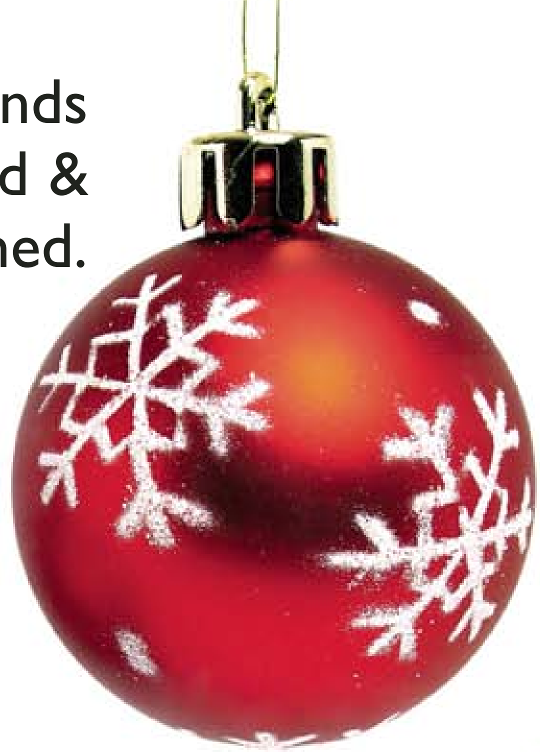

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SAFETY REMINDER

When building the boost power supply, remember that — depending on the components chosen in the design — high voltages can be generated. Care should be exercised to avoid electrical shock. Capacitors can hold energy after the power is removed from the circuit.

The High Voltage PIC PART 2

— by Robert Lang

In Part 1, we covered the theory of how a boost power supply works. We introduced pulse width modulation (PWM) and explained how to get the 18F2455 PIC to output a square wave with a given period and duty factor. We covered the important parameters in designing the boost power supply and used the free LTSPICE program to come up with a possible design.

This month, we will build the power supply designed last month on a printed circuit board. We will write the software needed to drive the PIC in a freely downloadable version of the C language. We will discuss the software that drives the A/D conversion, the LCD display, and the pulse width modulation. Then, we will program the microprocessor with the software. I will mention some of the pitfalls in designing a switching power supply and, finally, test the power supply.

Circuit Construction

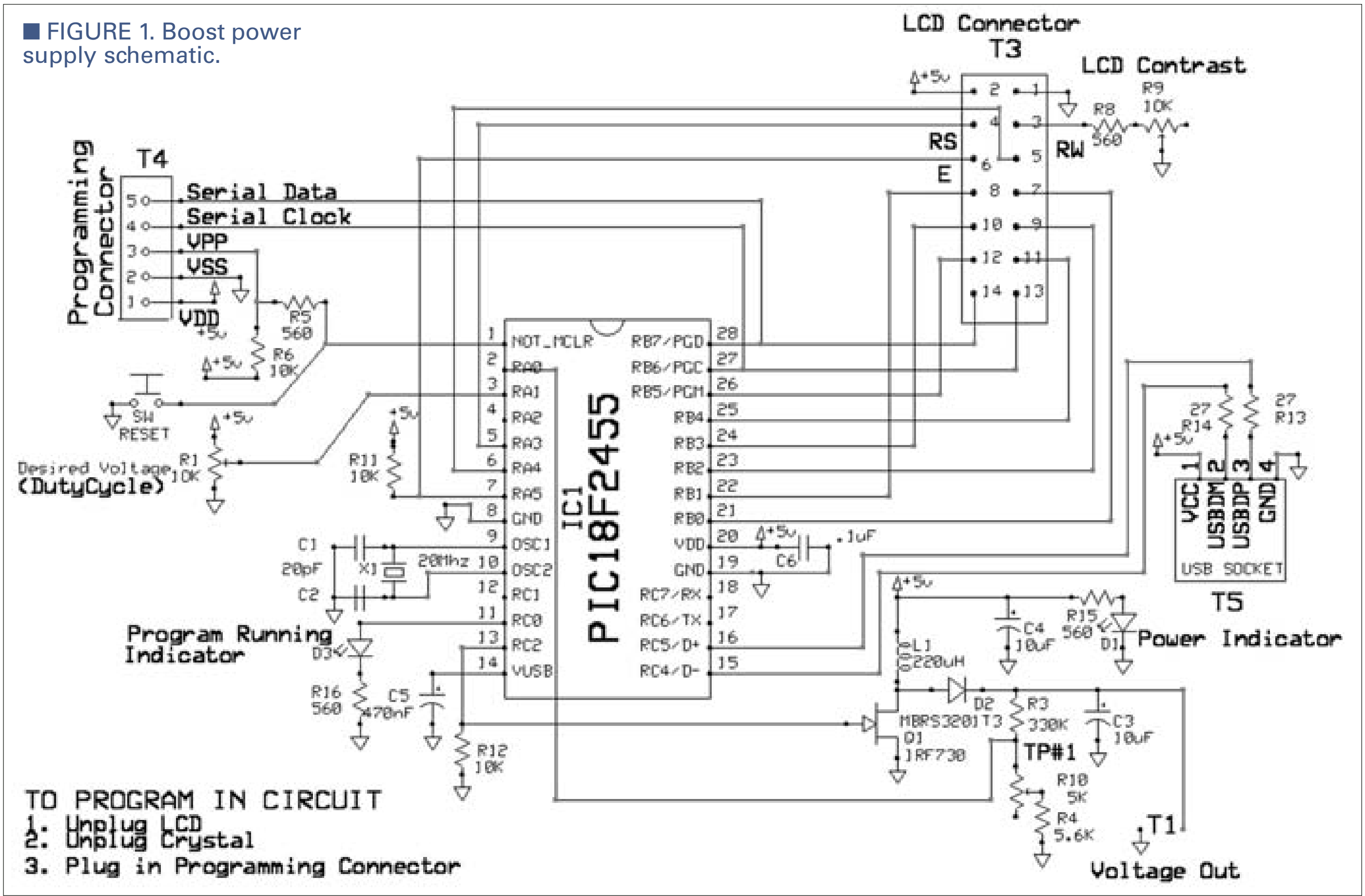
The boost power supply can easily be built on a breadboard or printed circuit board (PCB). Figure 1 is the schematic for the actual circuit that was built. Several components were added to the circuit from the basic design last month. The first of these is the 18F2455 microprocessor that was modeled as a square wave generator last month. In this circuit, the PWM output pin RC2 (pin 13 on the PIC18F2455) is used to drive the MOSFET that charges and discharges the inductor.

The PIC18F2455 can control an LCD display, so an optional LCD display was added along with the R9 potentiometer that is the LCD's contrast control. The LED D3 was added to flash periodically as an indicator that the PIC18F2455 is programmed and operating properly. The R10 potentiometer was added to allow a user to fine tune the LCD's display of output voltage to match the actual output voltage.

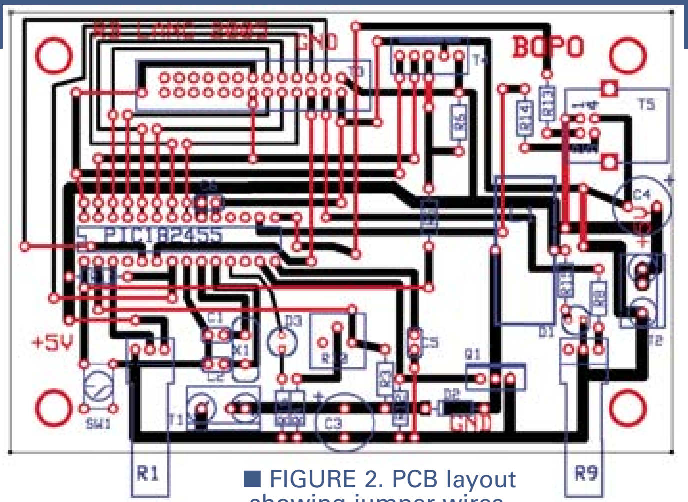
The R1 potentiometer was added to allow the user to set the desired output voltage. The microprocessor will attempt to maintain this output level by changing the ON time of the PWM. The output voltage at test point #1 is fed to the analog-to-digital converter point RA0 (pin 2 on PIC18F2455), where it is converted to a digital value. This digital value is compared to the desired output voltage, and the difference is used to increase or decrease the ON time of the PWM.

The programming connector — T4 — and its associated components, were added to allow the 18F2455 PIC to be reprogrammed without

■ FIGURE 1. Boost power supply schematic.



■ FIGURE 3.
Completed boost power supply on circuit board.



■ FIGURE 2. PCB layout showing jumper wires.

removing it from the circuit. The USB connector — T5 — was added to allow for experimentation using the USB as a five-volt power source.

The diode — MBRS3201T3 — is a 200-volt, three-amp Schottky diode that has a very low forward-voltage drop for an ultrafast rectifier. This means it offers very little resistance to the flow of current in one direction. The MBRS3201T3 is only available in a surface mount package.

After initial debugging, the boost power supply was built on a one-sided, 3 inch x 4.5 inch PCB using the pattern shown in Figure 2. The traces shown in red are component-side jumper wires. The completed circuit board is shown in Figure 3. Here are the steps for building this board:

Step 1: Solder all jumpers first, since some are beneath components that will be added later.
Step 2: Solder the surface mount diode — D2 — to the copper side of the PCB.
Step 3: Solder all resistors and the R10 potentiometer.
Step 4: Solder the sockets, T1-T6.
Step 5: Solder all capacitors.
Step 6: Solder remaining components.
Step 7: Plug the LCD into the T3 connector.

Vin is +5 volts DC. I added a USB port to the boost power supply, since +5 volts DC can be obtained directly from the USB port, eliminating the need for a five-volt DC power supply. The boost power supply requires about 250 milliamps at five volts to drive the output load at 200 volts and 2.5 milliamps. You should test your application's current requirements before powering from the USB port, since the USB port has a limit of one amp and might not be protected from overload.

When building the boost power supply, one tool that is very handy to have is an inductance/capacitance meter. Figure 4 shows one such meter measuring a 606 microhenry inductor. This meter — which costs about $50 — is useful for identifying the value of poorly marked inductors or capacitors.

■ FIGURE 4. Using an inductance-capacitance (LC) meter to measure an inductor.

Software Development

Using the free, C18 student edition C compiler, I wrote a program for the microprocessor to control switching the MOSFET. This free compiler is available from Reference [4] and integrates flawlessly into the MPLAB integrated development environment [5].

The C18 compiler also includes libraries of functions that can be linked directly into your application using the MPLINK linker. These libraries provide simplified control of hardware peripherals such as analog-to-digital converters, pulse width modulation, and timers.

In addition, the libraries provide 32-bit, floating-point math and trig functions, memory and string formatting functions, and character output functions [6]. I made use of these functions to keep the C program short and concise.

My initial plan was to use the floating-point math and output functions in the C18 library, but I found that C18 had no function to format floating-point for output. I also found that by limiting my math to integers, I could reduce the program size by 2,456 bytes in a 9,537 byte program. Thus, to reduce program size, all calculations use integer math.

The optional liquid crystal display (LCD) shown in the Parts List uses the Samsung KS0066 (S6A0069) controller. The C18 library routines were written for the Hitachi HD44780 LCD controller, so I modified them to work with the Samsung controller. These modified routines are included in the C18 source code.

The program consists of two parts. The MAIN program initializes the microprocessor and displays the information on the LCD. The interrupt routine handles the analog-to-digital (A/D) conversion of the desired and actual voltages, does the voltage comparisons, calculates the correction factors, and adjusts the PWM duty cycle. The desired voltage is input from an A/D of a potentiometer

on pin RA1. The measured voltage is from the A/D converter on pin RA0.

I used a resistor divider network to scale the output voltage to 0-5 volts. At an output voltage of 100 volts, the voltage across the 8 kΩ resistor combination (R4 and R10) is 2.37 volts, or 484 counts after digital conversion. Full scale on the A/D conversion is 1023/484*100, or 211 volts. I used this information to scale the VDES and VOUT readings to 0-211 volts. The R10 potentiometer can be adjusted so the combined resistance of R10 and R4 will cause the LCD to read VOUT=100.0 when the actual output is 100 volts.

Software Description

Main — The main program calls ADCInit() to initialize the analog-to-digital conversion, EnableInterrupts() to initialize timer and PWM functions, and LCDInit() to initialize the LCD. The program then goes into an infinite loop erasing the LCD, displaying voltages, erasing the LCD, displaying ON time in nanoseconds, erasing the LCD, and displaying the period in nanoseconds. Delays are inserted to allow time for the display to be read.

Key program constants are defined in common program memory: **PERI OD**=32000 is the period in nanoseconds of the PWM square wave. This value can range from 1-338,640 nanoseconds. **MAXVOLTS**=211 is the maximum output voltage of the power supply. This is determined by the values of R3, R4, and R10. **PERIOD_TIME_UNIT**=1332 is the time in nanoseconds, corresponding to one unit in the period (PR2) register and is equal to TOSC (20.8 ns) * TIMER2 prescaler (16) * 4 ~= 1332 ns.

EnableInterrupts() — This routine sets up and enables Timer0 for the timer interrupt. Timer2 is started since it is needed for the PWM function. OpenPWM1() is called to start the PWM function with the proper period.

ONTIME() — This routine calculates the voltage error from VDES-VOUT. The variable On_Time, is increased if the error is positive and decreased if the error is negative. On_Time is kept within a valid range for the PWM input. On_Time is a shared common value.

ADCInit() — This routine calls the OpenADC() library function to set up the A/D conversion on pins RA0 and RA1. This routine also sets up other PORTA pins as digital for use as control lines for LCD display.

ADCGet() — This routine will select RA0 and then RA1 for A/D conversion. It waits until the conversions are complete, then stores the values in variables VDES and VOUT. Values are 0-1,023 counts.

SendLCDCommand() — This will set up control lines and send a one-byte command to the LCD display.

SendLCDData() — This will set up control lines and send one byte of data to the LCD display.

WaitWhileBusy() — This routine will wait until the busy bit, RB7, is cleared by the LCD. The busy bit is checked once every five milliseconds.

LCDErase() — This routine will send the erase command, 0x01, to the LCD. The busy bit is checked before and after the command is sent.

LCD_Display_Rom() — This routine will display a string stored in program (ROM) memory.

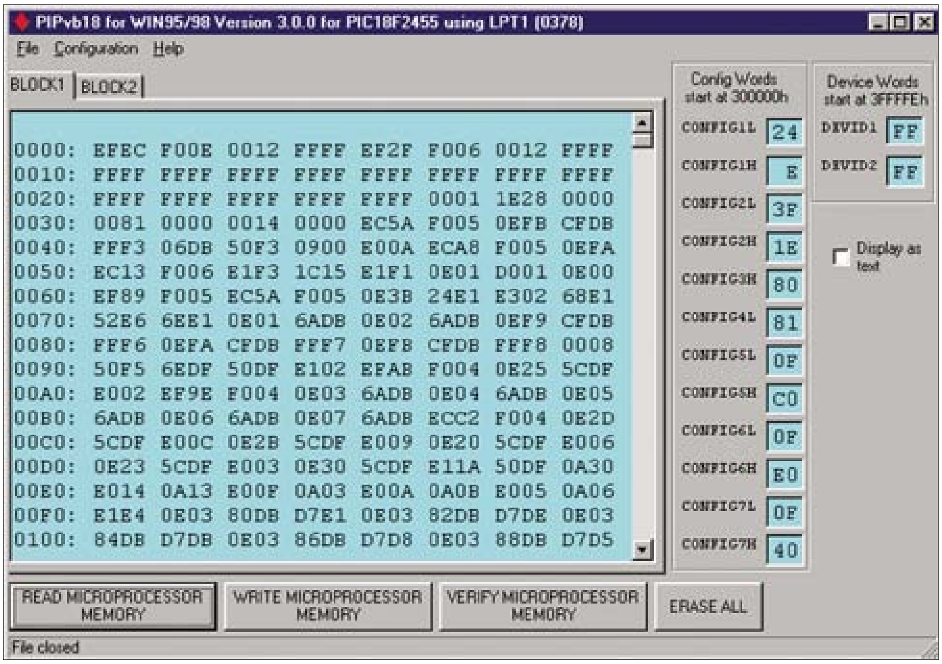
LCD_Display_Ram() — This routine will display a string stored in data (RAM) memory.

LCDInit() — The LCDInit() routine initializes the LCD display. Commands are sent to put the display in auto increment mode and turn the cursor on and the blinking off. The LCD is

PARTS LIST FOR BOOST POWER SUPPLY

Qty	Part ID	Description	Source-Reference/Part No.
2	T1,T2	Two screw terminals	1 / 164793
1	T3	26-pin socket	1 / 68371
1	T4	Programming connector	1 / 153699
1	T5	USB PCB connector	1 / 230957
1	T6	Two pin socket for crystal	1 / 167003
1	PCB	Printed circuit board kit	1 / 70412
1	SW	Reset switch (momentary contact)	1 / 122972
1	X1	20 MHz crystal	1 / 14517
2	C1,C2	22 pF disk capacitor	1 / 15405
1	C5	470 nF electrolytic capacitor	1 / 25558
1	C3	47 µF electrolytic capacitor, 250 V	1 / 330616
1	C4	2200 µF electrolytic capacitor, 16 V	1 / 133146
1	C6	0.1 µF	1 / 25523
2	R1,R9	10K potentiometer	1 / 241453
5	R2, R6,R7, R11,R12	10K resistor	1 / 29911
1	R3	330K ohm resistor	1 / 30883
1	R4	5.6K ohm resistor	1 / 31270
4	R5,R8,R15, R16	560 Ω resistor	1 / 31376
1	R10	5K potentiometer	1 / 43078
2	R13,R14	27 Ω resistor [1]*	1 / 30584
1	D1,D3	LED	1 / 206498
1	LCD1	Optional 20-character LCD	2 / 8087
1	D2	MBRS3201T3	3
1	IC1	Blank PIC18F2455 microprocessor	5
		Preprogrammed chip	8
1	Q1	IRF730 MOSFET	1 / 210551
1	L1	220 µH, 3.6 A inductor	1 / 371418

**[1] All resistors 1/4 watt*



■ FIGURE 5. PIC programming software.

erased by calling the LCDErase() routine. A message "BOOST POWER SUPPLY" stored in program memory is displayed by a call to LCD_Display_Rom. Appropriate delays are used until the LCD busy bit is available.

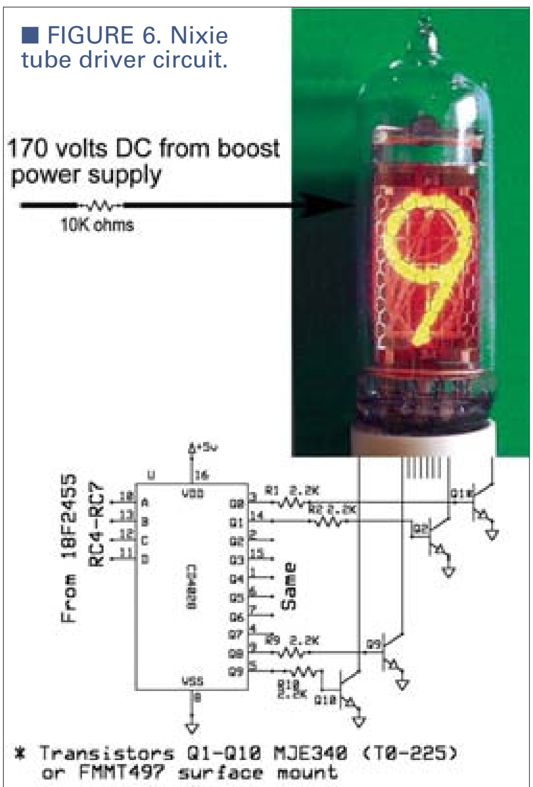
DisplayVoltages() — The Display Voltages() routine scales the VDES and VOUT counts from the A/D converter to 0.0-211.0 volts DC for display. All calculations use integer arithmetic to decrease the size of the program. Integer volts and tenths of volts are stored in separate variables. The sprintf() function from the C18 library is used to format a string for display, and the LCD_Display_Ram() function is used to output the string to the LCD.

DisplayONTIME() — This routine will display the value of the ON time. On_Time is converted to nanoseconds and displayed on the LCD using the sprintf() and LCD_ LCD_Display_Ram() functions.

DisplayPeriod() — This routine will display the period in nanoseconds on the LCD using the sprintf()and LCD_Display_Ram() functions.

Timer_handler() — Timer_handler() is the interrupt routine that is called every 1,000 microseconds when Timer0 overflows. This routine performs the A/D conversion by calling ADCGET(), calculates a new On_Time by calling subroutine ONTIME(), and modifies the PWM duty cycle by calling the C18 library function SetDCPWM1() with On_Time as the argument. The Timer0 interrupt flag is cleared and the timer is reloaded by a call to the C18 library function WriteTimer0().

■ FIGURE 6. Nixie tube driver circuit.



Programming the Microprocessor

The C compiler is used to compile and link the C source into the bopo.hex file. The next step in the process is to download the hex file to the PIC18F2455 chip. For this, you will need PIC programmer hardware and PIC programmer software for the PC (or you can order the preprogrammed chip from Reference [8]). The PIC programmer's connector plugs into the T4 connector in Figure 1.

There are lots of schematics for PIC programmers [9] and free PIC programmer software [10] on the Internet. I like the TAIT programmer hardware. It uses the PC's parallel port and the PIPVb programming software shown in Figure 5. Just make sure the programming software is tested on the operating system you are using and works for the PIC18F2455 since the programming algorithm was changed by Microchip for this PIC [11].

Switching Power Supply Pitfalls

There are many factors that need to be considered when designing a boost power supply. One of the most important considerations is the layout of the PCB. The following suggestions are taken from Reference [12]:

- Use a low electro-magnetic interference (EMI) inductor with a ferrite type closed core. Examples include toroid and encased E core inductors.
- Run the feedback trace as far from the inductor and noisy power supply traces as possible.
- Locate a low value ceramic input filter capacitor as close to the Vin pin of the IC as possible.
- Make sure all power traces are as short, direct, and thick as possible. Size PCB traces for maximum current to be carried — at least 15 millimeters per amp.
- Keep the inductor, output capacitor, and output diode as close to each other as possible. This will help to

reduce EMI radiated by the power trace.

- Arrange components so that the switching current loops curl in the same direction. This will prevent magnetic field reversal caused by the traces between the two half-cycles and reduce radiating EMI.
- Use the copper area on the PCB as a heatsink for components, if possible.
- Use a ground plane for the control circuit. Try to make the connections to the ground plane through vias rather than through PCB traces.

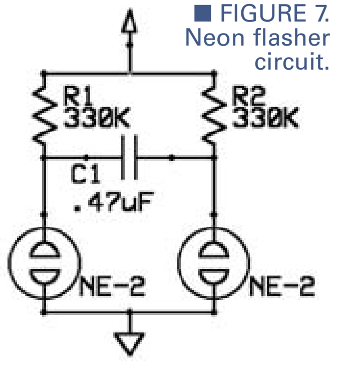
Sample Applications

Now that we have completed our boost power supply, let's use it to power an application. There are several applications we might use the boost power supply for. We could use it as a 13-volt, DC power supply to supply programming voltage for a USB PIC programmer [13]. Or, we could supply 170 volts DC at 2.5-4 mA to drive a Nixie tube [14]. Nixie tubes are the precursors to the alphanumeric LEDs of today. (See this month's project for Building a Nixie Clock.) They are no longer manufactured in the USA, but they can be found on eBay from sources in Russia and the Ukraine. Figure 6 shows additional circuitry necessary to drive a Nixie tube.

We will do a simple application involving neon lamps. The NE-2 is a cold-cathode neon gas discharge tube meant for use as an indicator light. It has two parallel electrodes sealed in a small glass envelope with neon gas. The discharge will start at about 65 volts, and the more current that flows, the more the orange discharge will cover the negative electrode. It only requires a few tenths of a milliamp to give full glow. For this reason, a current limiting device — like a resistor — is used.

The glow lamp cannot only be used as an indicator, but also as a useful circuit element. Figure 7 shows a simple circuit that can be connected to the boost power supply that will flash two neon bulbs alternately. Smaller values of the capacitors and resistors increase the flashing frequency, larger values slow the flasher down. The higher the voltage, the faster the lights will alternately flash. The capacitor should be non-polarized with a voltage rating of more than 100 volts. Figure 8 shows the working neon flasher hooked up to the boost power supply.

With the simple flasher circuit, we have the start of an oscillator. In the past, the tremolo circuit in the classic Fender guitar amplifier used a neon lamp and a CdS photocell.



■ FIGURE 7. Neon flasher circuit.

■ FIGURE 8. Working neon flasher.

Conclusion

We have now completed construction of the boost power supply that was designed last month. We developed the C software needed to drive the PIC. We discussed how the software handles the A/D conversion, the LCD display, and the PWM. We programmed the microprocessor with the software. We discussed some of the pitfalls in designing a switching power supply and, finally, used the power supply to power some applications. **NV**

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UNDERSTANDING

Digital Logic ICs

PART 4 — Modern CMOS Digital ICs

Ray Marston takes a close look at the popular '4000'- and '74'-series of modern CMOS digital ICs and at CMOS basic usage rules in this final installment.

BY RAY MARSTON

One of the most important events in the history of digital electronics was the development of the new IC technology known as CMOS in 1969. CMOS (Complementary-symmetry MOSFET) digital IC elements have major advantages over TTL types. They are simple and inexpensive, consume near-zero quiescent current, have a very high input impedance, can operate over a wide range of supply voltages, have excellent noise immunity, and are very easy to use.

In 1972, practical CMOS arrived on the commercial scene in the form of a brand-new medium-speed family of digital ICs known as the '4000'-series. This new family was not as fast as the TTL technology then in use in the rival '74'-series of digital ICs, but in the mid 1980s, a new high-speed type of CMOS was developed and introduced as a new member of the 74 family of devices. The advantages of this new 'fast' CMOS were so great that in 1994, it overtook TTL in popularity within the 74-series, finally making CMOS the most popular of all modern digital IC technologies.

This final episode explains the operating principles of these 4000- and 74-series CMOS devices, and describes CMOS basic usage rules.

CMOS Basics

The most basic element in any digital IC family is the digital inverter. Figure 1 (repeated from Part 1 of this four-part series) shows a basic CMOS inverter. It is a 'totem-pole' type of amplifier and consists of a complementary pair of enhancement-mode MOSFETs wired in series between the two supply lines, with p-channel MOSFET Q1 at the top and n-channel MOSFET Q2 below and with the MOSFET gates (which have a near-infinite DC input impedance) tied together at the input terminal and the output taken from the junction of the two devices. The pair can be powered from any supply in the 3V to 15V range. The basic digital action of the n-channel device is such that its drain-to-source path acts like an open-circuit switch when the input is at logic-0, or as a closed switch in series with a 400Ω resistor when the input is at logic-1. The p-channel MOSFET has the inverse of these characteristics, and acts like a closed switch plus a 400Ω resistance with a logic-0 input, and an open switch with a logic-1 input. The basic action of the CMOS inverter can be understood with the help of Figure 2.

Figure 2(a) shows the digital equivalent of the CMOS inverter circuit with a logic-0 input. Under this condition, Q1 (the p-channel MOSFET) acts like a closed switch in series with 400Ω, and Q2 acts like an open switch. The circuit thus draws zero quiescent current but can 'source' fairly large drive currents into an external output-to-ground load via the 400Ω output resistance (R1) of the inverter. Figure 2(b) shows the inverter's equivalent circuit with a logic-1 input. In this case, Q1 acts like an open switch, but Q2 (the n-channel MOSFET) acts like a closed switch in series with 400Ω; the inverter thus draws zero quiescent current under this condition, but can 'sink' fairly large currents from an external supply-to-output load via its internal 400Ω output resistance (R2).

Thus, the basic CMOS digital inverter can be used with any supply in the 3V to 15V range, has a near-infinite input impedance, draws near-zero (typically 0.01 µA) supply current with a logic-0 or logic-1 input, can source or sink substantial output currents, and has an output impedance of about 400Ω. Note that, unlike the TTL inverter, its output can swing all the way from zero to the full positive supply rail value, since no potentials are lost via saturation or forward-biased junction voltages, etc. Typically, a basic (mid 1970s style) CMOS stage has a propagation delay ranging from 12 ns when using a 12V supply, to 60 nS at 3V, etc.

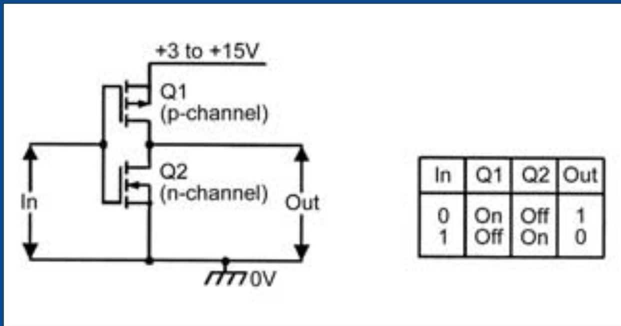


FIGURE 1. Circuit and Truth Table of a basic CMOS inverter.

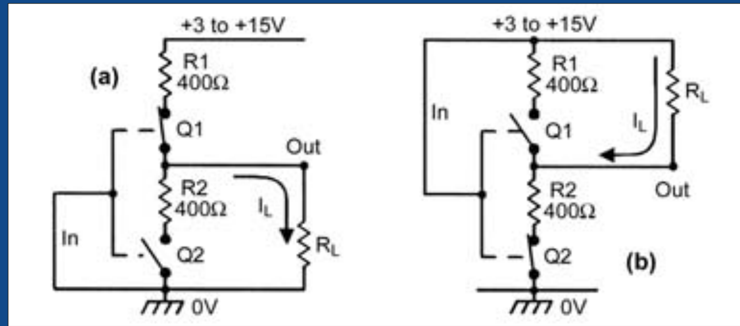


FIGURE 2. Equivalent circuit of the CMOS digital inverter with (a) logic-0 and (b) logic-1 inputs.

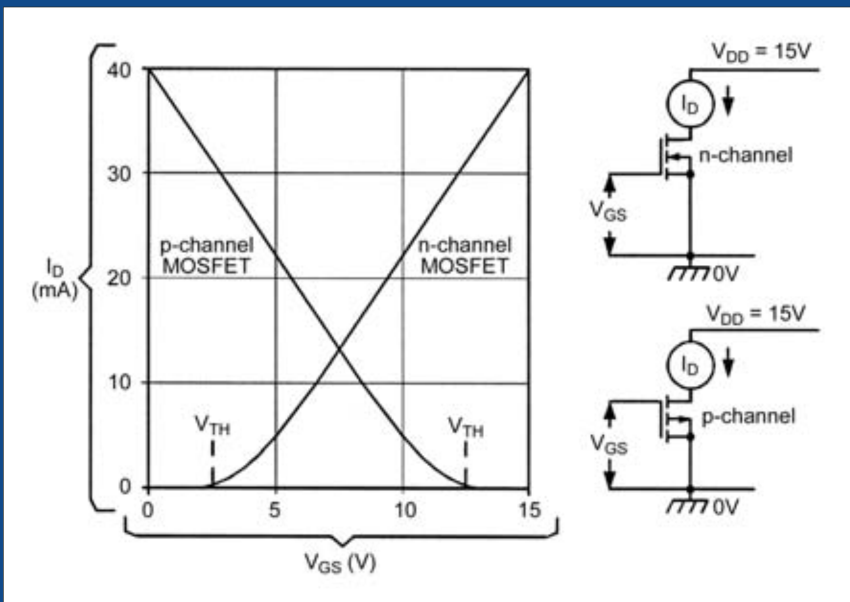


FIGURE 4. Typical gate-volts/drain-current characteristics of p- and n-channel MOSFETs operating from a 15V supply.

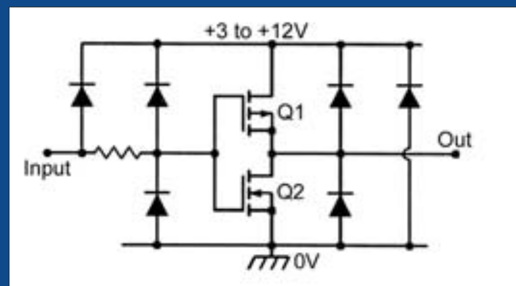


FIGURE 3. Basic 4000A-series inverter stage, with internal input and output protection networks.

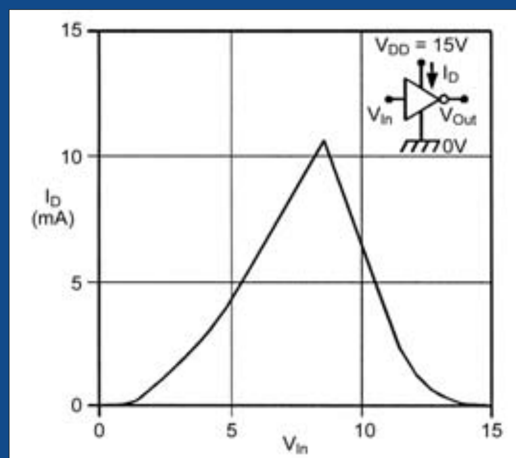


FIGURE 5. Typical drain-current transfer characteristics of the simple CMOS inverter.

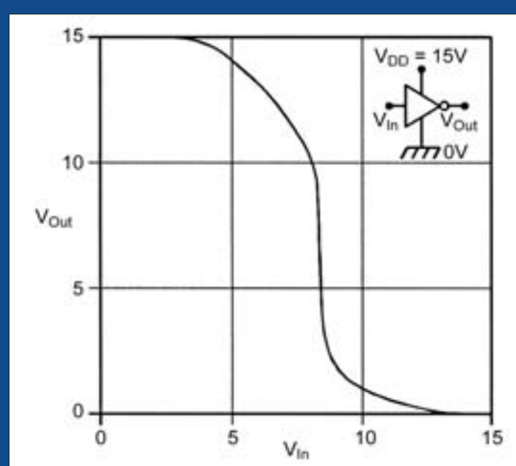


FIGURE 6. Typical voltage transfer characteristics of the simple CMOS inverter.

The '4000A'-Series of ICs

The initial 1972 range of digital ICs was known as the '4000A' series; it used the basic type of CMOS inverter shown in Figure 1, but incorporated extensive diode-resistor 'clamping' networks to protect its MOSFETs against damage from static charges, etc. Thus, a complete A-series inverter stage took the basic form shown in Figure 3.

Commercial testing of the early A-series range of CMOS devices quickly revealed a number of design problems. Their on-off resistance values were, for example, very sensitive to gamma radiation effects, thus limiting their value in outer-space projects, and they gave uneven 'high' and 'low' output impedances and propagation delays, etc. (i .e., they had poor output symmetry). But the most important problem was that their output switching levels were overly sensitive to the magnitudes of their input switching signals; the root cause of this problem can be understood with the aid of Figure 4, which shows the linear characteristics of the CMOS inverter's two MOSFETs when they are operated from a 15 volt supply.

Note in Figure 4 that each MOSFET acts like a voltage-controlled resistance. The n-channel device has a near-infine drain-to-source resistance at zero input voltage: the resistance remains high until the input rises to a 'threshold' value of about 1.5 to 2.5 volts, but then decreases as the input voltage is increased, eventually falling to about 400Ω when the input equals the supply line voltage. The p-channel MOSFET has the reverse of these characteristics. Thus, when the two MOSFETs are wired in series and used as a

15 volt basic CMOS inverter, they produce the typical drain-current transfer graph shown in Figure 5, and the voltage transfer graph of Figure 6; these graphs can be explained as follows.

Suppose in Figures 5 and 6 that the CMOS inverter's input voltage is slowly increased upwards from zero. The inverter current is near zero until the input exceeds the n-channel MOSFET's threshold voltage, at which point its resistance starts to fall and that of the p-channel MOSFET starts to increase. Under this condition, the inverter current is dictated by the larger of the two resistances; when the input is far less than half-supply volts, the n-channel MOSFET resistance is far greater than that of the p-channel device, so the output is high (at logic-1).

When the input is at a transition value somewhere between 30 and 70 percent of the supply voltage, the two MOSFETs have similar resistance values and the inverter acts as a linear amplifier with a voltage gain of about 30 dB and draws several milliamps of supply current. Under this condition, small changes of input voltage cause large changes of output voltage. When the input is further increased — well above half-supply volts — the resistance of the n-channel MOSFET falls below that of the p-channel device, and the output goes low (to logic-0). Finally, when the input rises above the threshold value of the p-channel MOSFET, it acts like an open switch, and the inverter current again falls to near zero.

Thus, the A-series type of inverter gives an output that switches fully between the supply rail values only if its input voltage swings well above and below its two internal threshold voltage values. Note (from Figure 5) that the CMOS draws a brief pulse of supply current each time it goes through a switching transition; the more often CMOS changes state in a given time, the greater are the number of current pulses that it takes from the supply and the greater is its mean current consumption. Thus, CMOS current consumption is directly proportional to switching frequency.

The '4000B'-Series of ICs

The defects of the 4000A-series were so severe that an improved CMOS series, known as the '4000B' or buffered series, was introduced around 1975, and the old 4000A-series was slowly phased out of production. The major feature of this new series is that each of its 'inverters' consists of three basic inverters wired in series, as shown in Figure 7, so that each 'buffered' inverter has a typical linear voltage gain of 70 to 90 dB and has the typical voltage transfer graph of Figure 8, in which any input below VDD/3 is recognized as a logic-0 input and any input above 2VDD/3 is recognized as a logic-1 input.

Other changes in the new series include greatly improved output-drive symmetry and immunity to gamma-radiation effects, new and better input and output protection networks (see Figure 9), and improved voltage ratings (usually to 15V maximum, but to 18V maximum in some manufacturer's versions, compared to 12V maximum in the original A-series).

One disadvantage of the B-series is that its propagation delays are larger than those of the old A-series. To counter this problem, a few new-generation devices are produced in an 'unbuffered' format (denoted by a 'UB' suffix), but incorporate all the other improvements of the B-series.

Typically, UB inverters have an AC gain of 23 dB at 10 volts, and are useful in several analog applications. Note that the bandwidth and propagation delays of a CMOS device vary with supply voltage and with capacitive output loading. Figure 10 lists the typical propagation delays of both UB and B-series inverters when used with supply values of 5V, 10V, and 15V when driving a 50 pF load.

The '4500B'-Series of ICs

The 4000B-series range of ICs consists mainly of fairly simple SSI or MSI devices such as logic gates and simple counters, etc. In the late 1970s and early 1980s, a number of more complex MSI and LSI B-type CMOS ICs such as encoders, decoders, and presettable counters (etc.), were introduced. These advanced devices carry '45XX' or '47XX' numbers, and are generally known as the 4500-series of CMOS ICs.

'Fast' CMOS ICs

In the early 1980s, engineers strove to design a really fast type of CMOS that could outclass LS TTL when operated from a five-volt supply and could thus become the dominant technology within the 74 series of ICs. Normal CMOS is based on MOSFET (Metal-Oxide Silicon FET) technology, and this is simply a variation of IGFET (Insulated-Gate FET) technology. Specifically, a MOSFET device is an IGFET device that uses metal-oxode gate insulation, and the first big step in developing 'fast' CMOS was to use silicon-oxide rather than metal-oxide gate insulation in the basic IGFETs.

This simple measure resulted in a dramatic reduction in the IGFET's internal input capacitance and an equally dramatic increase in operating speed. The next step was to apply these new IGFETs to the basic CMOS configuration. When this was done and significant changes were made in the element's geometry, the resulting device acted like normal CMOS but was as fast as LS TTL when operated from a five-volt supply and (unlike some other versions of CMOS) had excellent output drive capability. Strictly, this new device should have been given a special name such as CSOS (Complementary Silicon-Oxide Silicon FET), but instead was simply christened 'fast' CMOS.

Fast CMOS has many similarities with conventional 4000B-series CMOS. It is available in both buffered (triple-inverter) and unbuffered (single inverter) basic versions, and has all inputs and outputs protected via internal diode-resistor networks. It can (in most cases) use any supply in the 2V to 6V range, and when first introduced, was intended to replace many existing devices in the 74 series of ICs. Since then, however, it has also been used to make fast versions of many popular devices within the 4000B and 4500B series of ICs.

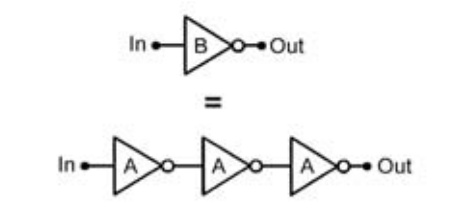


FIGURE 7. A B-series CMOS inverter can be made by wiring three A-series types in series.

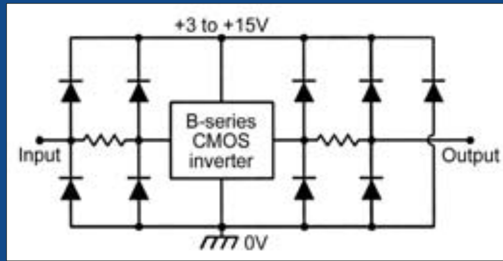


FIGURE 9. Basic 4000B-series inverter with typical input and output protection networks.

V_{DD}	Typical Propagation Delays	
	UB-types	B-series types
15V	20 nS	35 nS
10V	25 nS	50 nS
5V	40 nS	120 nS

FIGURE 10. Typical propagation delays of 4000B-series inverters when driving a 50 pF load.

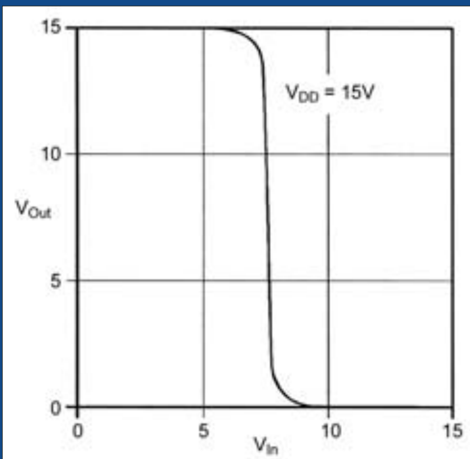
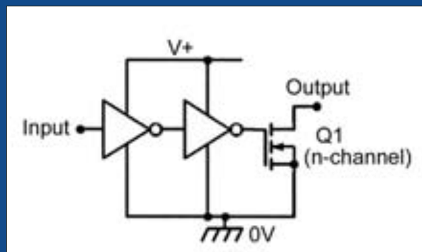
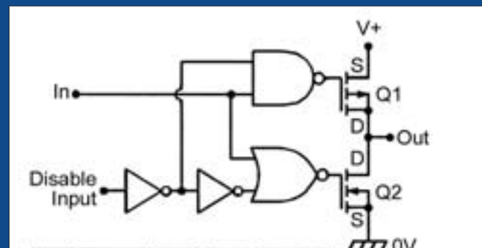


FIGURE 8. Voltage transfer graph of the Figure 7 B-series inverter.



In	Q1
0	Off
1	On

FIGURE 11. Basic CMOS inverter with open-drain output.



In	Disable Input	Q1	Q2	Out
0	0	Off	On	0
1	0	On	Off	1
X	1	Off	Off	Open Circuit

X = Don't care

FIGURE 12. Basic circuit of a three-state CMOS non-inverting buffer.

CMOS 74-Series Sub-Families

When the 74-series of IC first appeared in 1972, it was based entirely on TTL technology, which inherently consumes a fairly high quiescent current. In the late 1970s, a slightly modified version of standard CMOS (optimized for 5V operation) was introduced as a new 'C' sub-family within the 74-series range of devices, and offered the advantage of near-zero quiescent current consumption. This C sub-family was too slow and had too weak an output-drive capability to obtain great popularity, but in later years, the fast type of CMOS was developed specifically for use in the 74-series, as already described, and so far a total of five CMOS sub-families have been introduced in the 74-series, as follows:

• *Standard (C) CMOS (now obsolete).* This was virtually normal MOSFET-type CMOS in a 74-series format. Typically, a single 74C00 two-input NAND gate consumed about 15 mW at 10 MHz, and had a propagation delay of 60 nS at 5V.

• *High-speed (HC) CMOS.* Introduced in the early 1980s, this is the basic fast silicon-oxide version of CMOS, and gives speed performances similar to LS TTL, but with CMOS levels of power consumption. HC 74-series devices using this technology have CMOS-compatible inputs. Typically, a single 74HC00 two-input NAND gate consumes less than 1 µA of quiescent current, and has a propagation delay of 8 nS at 5V.

• *High-speed (HCT) CMOS.* These are fast HC-type devices, but have TTL-compatible inputs and are meant to be driven directly from TTL outputs. Typically, a 74HCT00 two-input NAND gate consumes less than 1 µA of quiescent current and has a propagation delay of 18 nS.

• *Advanced high-speed (AC) CMOS.* In the late 1980s, further advances in high-speed CMOS design and fabrication techniques yielded even better speed performances. AC 74-series devices using this technology have CMOS-compatible inputs. Typically, a 74AC00 two-input NAND gate has a propagation delay of 5 nS.

• *Advanced high-speed (ACT) CMOS.* These are AC-type devices, but have TTL-compatible inputs and are meant to be driven from TTL outputs. Typically, a 74ACT00 two-input NAND gate has a propagation delay of 7 nS.

Basic CMOS Circuit Variations

There are three important variations of the basic CMOS circuit that are often used in ICs in the medium-speed 4000B-series and fast 74-series ranges of devices. The first of these is the 'open drain' configuration, which is used in some inverters and buffers, etc. Figure 11 shows a typical open-drain inverter, which is configured like a normal high-gain three-stage CMOS inverter except that the final stage consists of a single n-channel enhancement-mode IGFET (Q1) that has its drain connected directly to the circuit's output terminal. The circuit's action is such that Q1 is cut off when the input is at logic-0, and is driven on when the input is at logic-1. The circuit can be used to directly drive an external load that is connected between 'OUT' and the +ve supply rail, in which case the load activates when a logic-1 input is applied.

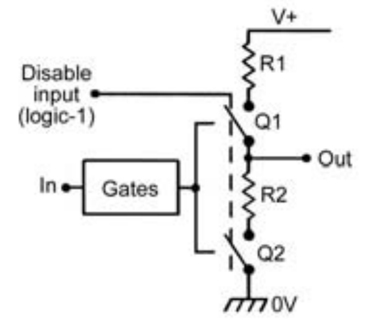


FIGURE 13. Equivalent of a three-state buffer circuit in its third high-impedance state.

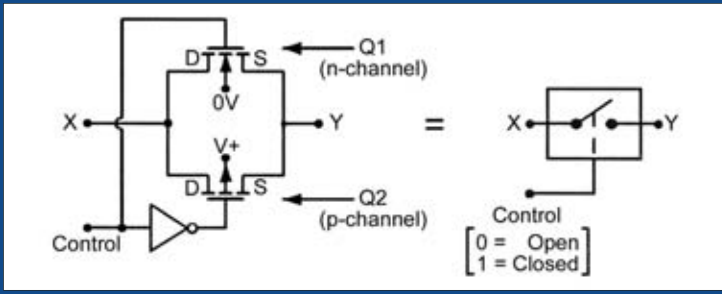


FIGURE 14. Basic CMOS bilateral switch or transmission gate.

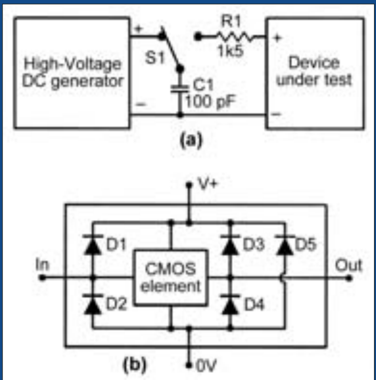


FIGURE 16. (a) Typical electrostatic discharge test circuit, and (b) simple equivalent of a CMOS digital IC element.

	LS TTL	4000B CMOS	4000UB CMOS	74HC CMOS	74HCT CMOS	74AC CMOS	74ACT CMOS
Supply Voltage range	4.75 - 5.25V	3 - 15V	3 - 15V	2 - 6V	4.5 - 5.5V	2 - 6V	4.5 - 5.5V
Quiescent Current (per gate)	0.5 mA	.01 µA	.01 µA	.02 µA	.02 µA	.02 µA	.02 µA
Propagation Delay (per gate)	9 nS	125 nS @ 5V 50 nS @ 10V 40 nS @ 15V	90 nS @ 5V 50 nS @ 10V 40 nS @ 15V	8 nS @ 5V	10 nS @ 5V	5 nS @ 5V	7 nS @ 5V
Maximum operating frequency (counter)	40 MHz @ 5V	2 MHz @ 5V 5 MHz @ 10V 6 MHz @ 15V	—	40 MHz @ 5V	—	100 MHz @ 5V	—
Fan-out [@ 5V, to LS TTL inputs]	20	1	1	10	10	60	60

FIGURE 15. Table showing general characteristics of LS TTL and the six major CMOS digital IC types.

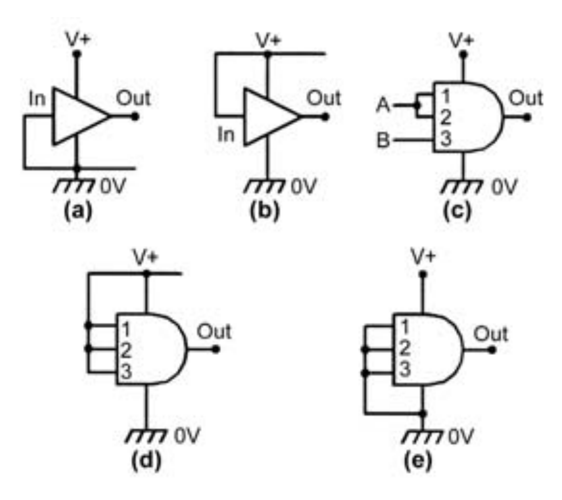


FIGURE 17. Alternative ways of connecting unwanted CMOS inputs (see text).

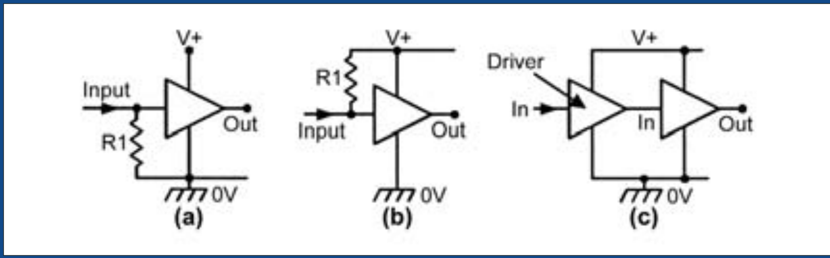


FIGURE 18. All used CMOS inputs must be tied to definite logic levels (see text).

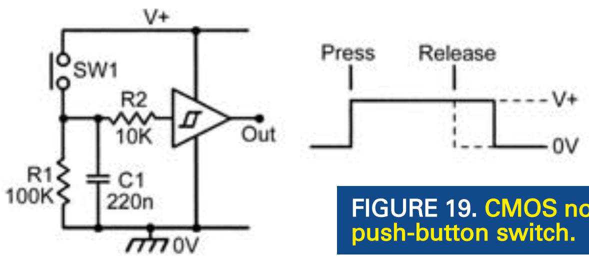
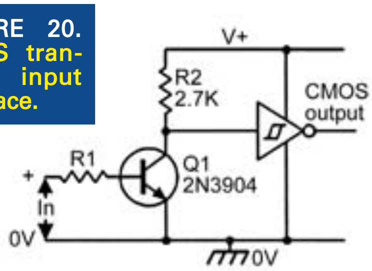


FIGURE 19. CMOS noiseless push-button switch.

FIGURE 20. CMOS transistor input interface.



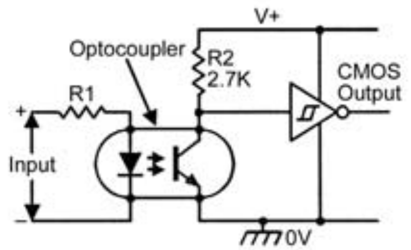


FIGURE 21. CMOS optocoupler input interface.

The second variation concerns the use of a 'three-state' type of output that in normal use gives a conventional logic-0 or logic-1 low-impedance output, but can also be set to a third state in which the output is effectively open-circuit. This facility is useful in allowing several outputs or inputs to be wired to a common bus and to communicate along that bus by ENABLING only one output and one input device at a time.

Figure 12 shows the typical circuit of a non-inverting buffer of this type, together with its truth table. Thus, when the DISABLE INPUT control is at logic-0, the circuit gives normal 'buffer' operation; under this condition, Q1 is driven OFF and Q2 is driven ON when IN is at logic-0, thus driving OUT to logic-0. The reverse of this action is obtained when the input is at logic-1. When the DISABLE INPUT control is set to logic-1, both Q1 and Q2 are driven OFF, irrespective of the state of the IN input, and under this condition, OUT is effectively disabled, and acts as an open circuit. Figure 13 shows the simplified equivalent circuit of this buffer when it is in its high-impedance output state.

The third CMOS circuit variation is that of the 'bilateral switch' or transmission gate. The basic action of any enhancement-mode IGFET is such that its drain-to-source path acts like a near-perfect unidirectional switch: When the IGFET is OFF, the path acts like an open circuit, and when it is ON, it acts like a low-value resistor and (unlike a bipolar transistor) does not suffer from saturation-voltage problems, etc. When turned on, an n-channel IGFET passes current from drain-to-source, and a p-channel IGFET passes current from source-to-drain. Thus, a near-perfect bidirectional or bilateral electronic switch can be made by wiring an n-channel and a p-channel IGFET in parallel (source-to-source and drain-to-drain) and driving their gates in anti-phase, as shown in Figure 14.

Here, both IGFET paths are effectively open when the CONTROL input is at logic-0, and closed when the CONTROL input is at logic-1. Under the closed condition, current can flow from X to Y via Q1, or from Y to X via Q2; current can thus flow in either direction between these points, and the circuit thus simulates a simple electro-mechanical switch.

CMOS Basic Usage Rules

CMOS ICs are very easy to use. They are very tolerant of supply voltage variations and, unlike TTL types, present very few input-drive/output-drive matching problems. There are, in fact, only seven basic usage themes to consider when dealing with CMOS which are: Type selection; Handling CMOS; Power supplies; Input signals; Unused inputs; and Interfacing.

Type Selection

The question "Which CMOS family should I use?" can easily be answered with the help of Figure 15, which lists the major characteristics of the six readily-available modern CMOS sub-families and compares them with those of LS TTL. Of these types, the 4000UB sub-family is only available in the form of a few simple buffer and inverter ICs, and should be regarded as a simple variant of the main 4000B sub-family. The 74HCT and 74ACT types are meant to be directly driven from TTL outputs, and are of use only in a few specialized applications.

Of the remaining three CMOS sub-families (4000B, 74HC, and 74AC), the 4000B sub-family can be used in any application that requires the use of a supply in the range of 3V to 15V and in which maximum operating frequencies do not exceed 2 MHz at 5V, or 6 MHz at 15V. Alternatively, if supply voltages are restricted to the 2V to 6V range, the 74HC sub-family can be used to operate at frequencies up to 40 MHz at 5V, or the 74AC sub-family at frequencies up to 100 MHz at 5V.

Note that all TTL ICs have special input-drive requirements, and the fan-out numbers in Figure 15 show how many parallel-connected standard LS TTL inputs can be directly driven from the output of each listed sub-family member. Thus, 4000B CMOS can only drive one such input, but 74HC and HCT CMOS can each drive 10 such inputs, and 74AC and ACT can each drive up to 60 LS TTL inputs.

Handling CMOS

CMOS is based on high-impedance IGFET technology, which — when being handled — is easily damaged by high-voltage static charges of the type that can build up on the body of the person handling them. All modern CMOS digital ICs incorporate extensive internal diode-clamping circuitry that is designed to protect their internal IGFETs against damage from reasonable amounts of this type of static discharge when the IC is being handled.

Figure 16(a) shows the basic laboratory circuit that is used — when testing CMOS ICs — to simulate reasonable values of static discharge from a human body; C1 has a value of 100 pF and simulates the typical body capacitance of a charged human adult, and R1 has a value of 1.5K and simulates the body's typical discharge resistance. When a CMOS IC is being given evaluation tests, C1 is charged to a high-value test voltage via S1, and is then applied to two of the IC's test points via S1 and R1. A basic CMOS element has four terminals (IN, OUT, V+, and 0V), and thus has a total of 12 possible two-pin test permutations. The test circuit is applied to each of these two-pin permutations in a full test sequence. Typically, modern CMOS digital ICs are expected to survive a test voltage of 2.5 kV in all of these test modes.

Figure 16(b) shows the basic form of a CMOS element's internal protection circuitry. Here, D1 or D2 conduct if IN tries to go above V+ or below 0V; D3 or D4 conduct if OUT tries to go above V+ or below 0V. D5 conducts if 0V tries to go above V+; D5 also conducts in the zener mode if V+ goes more than about 20V above 0V.

It is important to understand the meaning of these CMOS static discharge protection tests. Suppose that a 3 kV test voltage is applied between the IC's reverse-connected

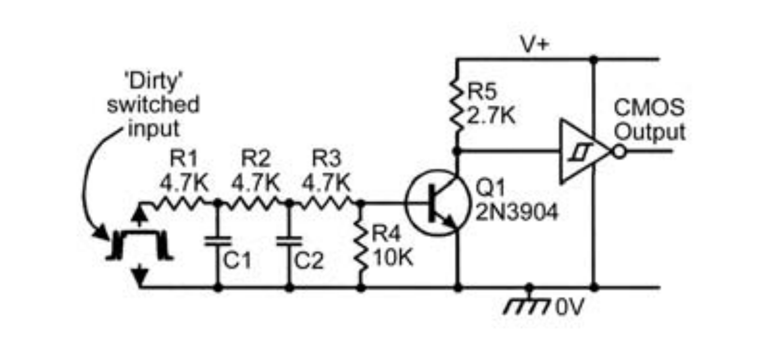


FIGURE 22. CMOS dirty-switching input interface.

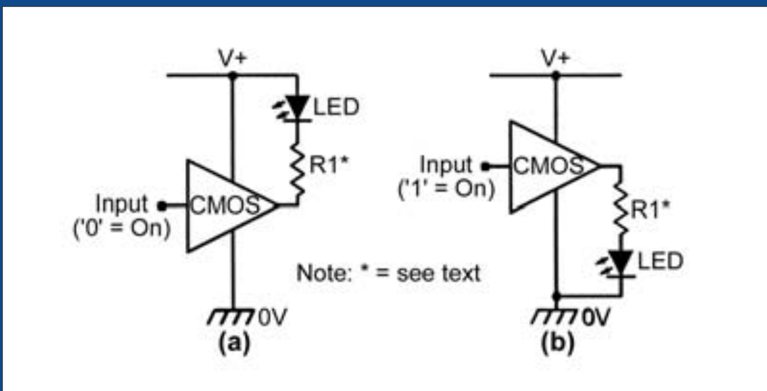


FIGURE 25. LED-driving output interface, using non-inverting CMOS elements.

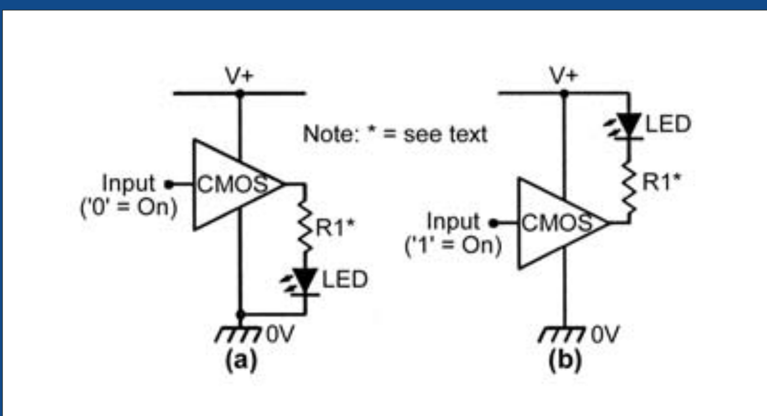


FIGURE 26. LED-driving output interface, using inverting CMOS elements.

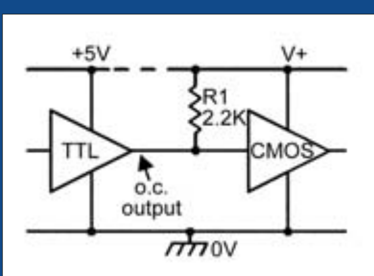


FIGURE 27. TTL (open collector output) to CMOS interface, using common or independent +ve rails.

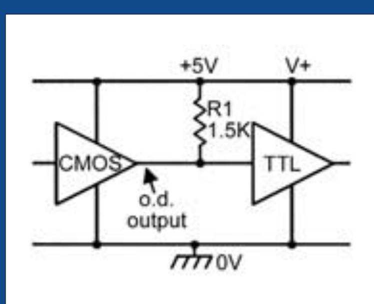


FIGURE 28. CMOS (open drain output) to TTL interface.

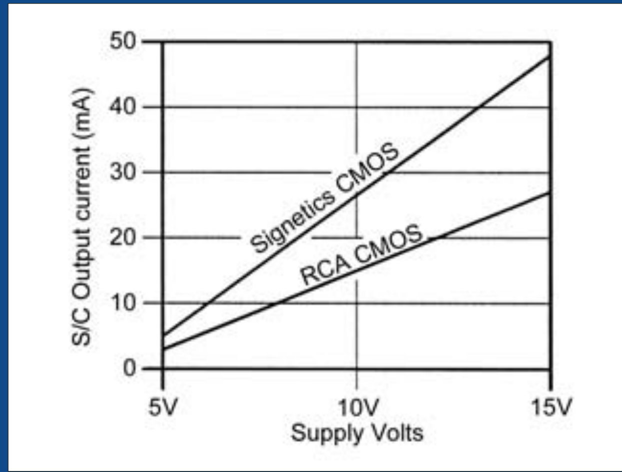


FIGURE 23. Typical 4000B-series short-circuit output currents (at 25 OC).

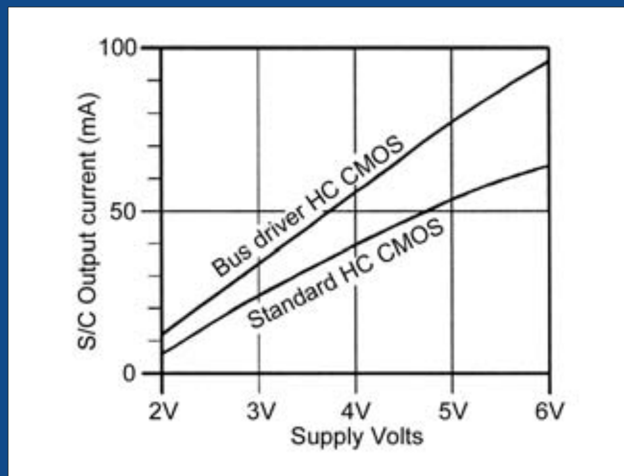


FIGURE 24. Typical 74HC series short-circuit output currents (at 25 OC).

0V and V+ pins. Under this condition, D5 is forward biased, and C1 discharges via D5 and R1; R1 limits C1's peak discharge current to 2A and gives it a basic time constant of 150 nS. Thus, D5 passes only a very brief spike of forward current as C1 discharges. If D1's thermal time constant is very long compared to the period of the spike, it may not suffer damage from this test, even though it can only handle normal DC currents of (say) 25 mA maximum. Note that the peak voltage appearing across D5 in this test is roughly 1V; most of C1's 3 kV discharge voltage is lost across R1.

The protection networks used in CMOS ICs are not designed to be effective against massive values of static discharge, such as the several thousand volts that may be generated by a person vigorously prancing about on a nylon carpet, etc. Consequently, when handling naked CMOS ICs, always take sensible precautions against the build-up of large static charges. Do not wear nylon clothing or use nylon mats/carpets in the workshop, and make sure that soldering irons, etc., are correctly grounded.

To be really safe, wear a grounded metal wrist

strap when working with CMOS, particularly when soldering. Note, however, that in reality it is very unlikely that you will ever damage a CMOS IC in normal handling, even if you are foolish enough not to wear a grounded wrist strap.

Power Supplies

CMOS ICs of the 4000B and 74HC and 74AC types are designed to operate over a wide range of supply voltages, and can thus be powered from batteries or from regulated or unregulated power supplies. 74HCT and 74ACT types, however, are designed to operate from supplies in the 4.5V to 5.5V range, and must be powered from low-impedance, well-regulated supplies of the types shown in Figures 1 to 3 of last month's article.

All CMOS ICs generate fast pulse-switching edges. Consequently, most CMOS circuits should be used with a PCB that is designed to give excellent high-frequency supply decoupling to each IC. In general, the PCB's supply and ground-rail tracks must be as wide as possible (ideally, the 0V track should take the form of a ground plane), all connections and inter-connections should be as short and direct as possible, the PCB's supply rails should be liberally sprinkled with 4.7 µF Tantalum electrolytic capacitors (at least one per 10 ICs) to enhance l.f. decoupling, and with 10 nF disk ceramics (at least one per four ICs, fitted as close as possible between an IC's supply pins) to enhance h.f. decoupling.

When experimenting with CMOS ICs, never allow the power supply to be connected in the wrong polarity, since this will cause heavy supply currents to flow through the IC's protective diode networks (specifically, through D5 in Figure 16) and cause instant damage to the IC's substrate.

Input Signals

When using CMOS, all IC input signals must — unless the IC is fitted with a Schmitt-type input — have very sharp rising and falling edges. If rise or fall times are too long, they may allow the input terminal to hover in the CMOS element's linear zone long enough for the element to burst into wild oscillations and generate spasmodic output signals that may disrupt associated circuitry (such as counters and registers, etc). If necessary, slow input signals can be converted into fast ones by feeding them to the IC's input terminal via CMOS Schmitt elements.

One possible way of damaging CMOS is via a very low impedance input or output signal that is either connected to the CMOS when its power supply is switched off, or is of such large amplitude that it forces the input terminal well above the positive supply line or below the zero-volts rail, thus causing a damaging current to flow through one or more of the IC's protection diodes (specifically, through Figure 16's input diodes D1 or D2, or output diodes D3 or D4). The possibility of such damage can be eliminated by wiring a 1K resistor in series with each input/output terminal to limit such currents to safe values of a few milliamps.

Unused Inputs

Unused CMOS input terminals must never be allowed to simply float, but must always be tied to definite logic levels by either connecting them directly to the supply or ground rails (depending on the IC's logic requirements), or to some other point with well defined logic levels. Figure 17 shows some of the available options. If the unwanted input is on a multi-input gate, it can be disabled by shorting it to one of the gate's used inputs, as in Figure 17(c), where a three-input AND gate is shown used as a two-input type. If the IC is a multiple gate type in which an entire gate is unwanted, the gate should be disabled by tying all of its inputs to a common high or low point, as in (d) and (e).

All used CMOS input terminals must also be tied to definite logic levels, and must never be allowed to float. Figure 18 shows three commonly used options. In (a), the input is normally tied low by R1, and in (b) it is normally tied high by R1. In (c), the input is direct-coupled to the output of a driving stage, which determines the input logic level.

Interfacing

An interface circuit is one that enables one type of system to be sensibly connected to a different type of system. In a purely CMOS system, in which all ICs are designed to connect directly together, interface circuitry is usually needed only at the system's initial input and final output points, to enable them to merge with the outside world via items such as switches, sensors, relays, and indicators, etc.

Occasionally, however, CMOS ICs may be used in conjunction with other logic families (such as TTL), in which case an interface may be needed between the different families. Thus, as far as CMOS is concerned, there are three basic classes of interface circuit, which are: Input interfacing, Output interfacing, and Logic family interfacing.

Input Interfacing

The digital signals arriving at the inputs of a CMOS system must be clean ones with well-defined logic levels and with fast rise and fall times. It is the input interfacing circuitry's task to convert external input signals into this format. Figures 19 to 22 show four simple examples of such circuitry; these circuits are similar to the TTL designs shown in last month's Figures 6 to 9, but must use CMOS Schmitt elements and can use any positive supply rail voltage within the operating limits of the CMOS element.

The Figure 19 circuit is designed to clean up the dirty switching signals of push-button switch SW1 and convert them into a form suitable for driving a normal CMOS input. Here, the input of the Schmitt buffer is tied to ground via R1 and R2 and is normally low. When SW1 is closed, C1 rapidly charges up and drives the Schmitt output high, but when SW1 opens again, C1 discharges relatively slowly via R1, and the Schmitt output does not return low again until roughly 20 mS later. The circuit thus ignores the transient switching effects of SW1

noise and contact bounce, etc., and generates a clean output switching waveform with a period that is roughly 20 mS longer than the mean duration of the SW1 switch closure.

Figure 20 shows a circuit that can be used to interface almost any clean digital signal to a normal CMOS input. Here, when the input signal is below 500 mV (Q1's minimum turn-on voltage), Q1 is cut off and the inverting Schmitt's output is at logic-0. When the input is significantly above 600 mV, Q1 is driven on and the Schmitt output goes to logic-1. Note that the digital input signal can have any maximum voltage value, and R1 is chosen to simply limit Q1's base current to a safe value.

Figure 21 is a simple variation of the above circuit, with the transistor built into an optocoupler; the circuit action is such that the Schmitt's output is at logic-0 when the optocoupler input is zero, and at logic-1 when the input is high; note that the optocoupler provides total electrical isolation between the input and CMOS signals.

Finally, Figure 22 is another simple circuit variation, with the basic digital input signal fed to Q1's base via the R1-C1-R2-C2 low-pass filter network, which eliminates unwanted high-frequency components and thus can convert very dirty input signals (such as those from vehicle contact-breakers, etc.) into a clean CMOS format.

Output Interfacing

CMOS totem-pole output stages are designed to source or sink fairly high peak values of output current. Consequently, if the output is shorted directly to the IC's zero-volts or positive supply rail, the resulting DC output currents can, in some cases, be so high that the IC may be damaged. Thus, when a CMOS IC is used to drive a DC load, its load current must always be limited to a safe value.

Figure 23 shows the typical short circuit output currents of two different manufacturer's 4000B-series CMOS output stages over the 5V to 15V operating voltage range. In practice, the maximum DC values of these output loads must be limited to 10 mA of current or 100 mW of power dissipation, whichever is the lower of these values.

Figure 24 shows the typical short-circuit output currents of standard and bus driver versions of 74HC-series CMOS output stages over the 2V to 6V operating voltage range. In practice, the maximum DC values of these currents must be limited to 25 mA in standard HC types, and 35 mA in bus driver HC types.

The only time this current limiting matter is likely to present any real problem is when using CMOS to drive some type of LED load (including those at the inputs of optocouplers, etc.). Figures 25 and 26 show basic ways of driving an LED via non-inverting or inverting CMOS elements. Note in these circuits that

R1 sets the LED's ON current, and has a value of [(V+ - Vs)/I] - Rx, where V+ is the supply voltage, Vs is the LED's saturation voltage (typically 2.0 to 2.5 volts), I is the LED's ON current (in amps), and Rx is the CMOS elements saturation resistance (and varies widely with voltage, current, and with individual ICs).

Typically, however, Vs equals 2.2V, and Rx has an approximate value of 100Ω in a standard 74HC output or 70Ω in a bus driver output, or 500Ω in a standard 4000B output. Thus, to set the LED current at 10 mA, R1 needs a value of about 180Ω in a 5V standard 74HC circuit, 220Ω in a 5V bus driver 74HC circuit, 270Ω in a 10V 4000B circuit, or 820Ω in a 15V 4000B circuit.

Note that CMOS outputs can be used to drive any of the basic TTL output interface circuits shown in Figures 12 to 17 in last month's Part 3 of this series by simply wiring a current-limiting resistor in series with the CMOS output, to limit its output current to a safe value.

Logic Family Interfacing

It is generally bad practice to mix different logic families in any system, but on those occasions where it does occur, the mix is usually made between TTL and CMOS devices. Figures 18 to 23 of last month's article showed six basic ways of interfacing TTL and CMOS ICs. Note that 74HCT and 74ACT types of CMOS ICs are designed to be directly driven from TTL outputs, without need for special interfacing methods. Also note that standard 4000B-series and 74CXX-series CMOS elements have very low fan-outs and can only drive a single standard TTL or LS TTL element, but 74HCXX-series (and 74ACXX-series) CMOS elements have excellent fan-outs and can directly drive up to two standard TTL inputs, or 10 LS TTL inputs, or 20 ALS TTL inputs.

Most TTL ICs with open-collector (OC) outputs have output-voltage ratings of at least 15V (but the main IC has a normal 5V rating), and can be interfaced to the input of a CMOS logic IC by using the connections shown in Figure 27. Here, R1 acts like a pull-up resistor, and the CMOS IC can either share the 5V supply of the TTL IC, or can use its own 5V to 15V positive supply rail. Similarly, a CMOS IC with an open-drain (OD) output can be interfaced to a normal TTL input by using the connections shown in Figure 28 but, in this case, the two ICs must share a common 5V supply rail.

CMOS Supply Pin Notations

Most digital ICs have only two supply pins, one of which connects to a circuit's positive supply rail, and the other to the zero volts rail. In TTL ICs, these pins are conventionally notated VCC and GND respectively, with the VCC notation implying that the positive rail usually connects to the collector sides of the IC's internal transistors.

When 4000-series CMOS ICs were first introduced, the supply pins were renamed VDD and VSS respectively, implying that the positive rail usually connects to the drain side of the IC's internal IGFETs, and the zero-volts rail to the source sides. These notations are, in fact, quite ambiguous, but are still widely used in CMOS manufacturer's data books.

When CMOS was first used as a C sub-family in the 74-series range of ICs, its supply pins were renamed VCC and GND, to comply with normal TTL conventions, and this system has subsequently been used on all other CMOS sub-families used in the 74-series of ICs. In recent times this same system has started to be used on the 4000-series of CMOS ICs, as well, and the current situation is that a CMOS IC positive supply terminal may be notated VCC or VDD, depending on the whim of the individual manufacturer. NV

ONCE IN A BLUE MOON

How often have you been typing on your pedestrian beige keyboard and wished that it could be a vibrant, more trendy color? You know, a color like purple, red, or blue. Well, the folks at Saitek Industries (**www.saitekusa.com**) must've thought that we were all pining for oddly colored keyboards.

The newly released Eclipse II computer keyboard is equipped with a backlighting feature that can cast one of three user-selectable colors (once again, for the color impaired: purple, red, or blue) up through the laser-etched keys.

These glowing keys are tucked away inside a weighted silver case that is backed with rubber feet. In another nod towards users, this keyboard also features unique "media keys." These keys mimic the control keys found on media players. In theory, you can use the Eclipse II's media keys for controlling the play of your media files without accessing the application's onscreen interface with your mouse. The Eclipse II retails for $69.

AN ELEPHANT'S EAR

■ Klipsch Audio Technologies iGroove HG.

Klipsch Audio Technologies (**www.klipsch.com**) has dusted off their original silver iGroove powered speaker system for MP3 music players. The new model, iGroove HG, sports an eye-catching high-gloss black finish and unique curved shape.

Based on the popularity of Apple's recent shift into black iPods, Klipsch felt that a new iGroove was warranted. Hence, the iGroove HG.

While the iGroove HG is synonymous with iPod, it isn't restricted to playing music from docked iPods. A special line in port enables the iGroove HG to connect to any music player that features a similar headphone output jack.

Employing dual 2.5-inch woofers, crossovers, and dual one-inch MicroTractrix™ Horn-loaded tweeters, the iGroove HG is the only speaker system in this category utilizing horn technology. And Klipsch claims that horn technology is able to produce a genuine, lifelike sound, as well as produce more sound output using less energy.

In my tests, I felt that the iGroove HG generated just a little too much bass presence. Even when the output from my iPod nano was tamed down

with various EQ (equalizer) settings, the output still seemed more akin to a late night Friday bar scene rather than a somber Saturday evening at home.

The iGroove HG is available through all of the usual outlets with a retail price of $249.99. Oh, and you bargain hunters out there can purchase factory refurbished models of the iGroove HG directly from Klipsch saving over $100 off the retail price.

GLEE FOR THREE

At the 6th Annual Embedded Systems Conference-Taiwan (**www.taiwan.escasiaexpo.com**), there were three products that caught our eye.

The first was Tibbo Technology's new 100BaseT Ethernet-to-serial Module in RJ45 Form Factor. Very compact and highly integrated, the module features built-in Ethernet, RJ45 connector, and four status LEDs. Being a true one-component Ethernet-to-serial solution, the EM202 has a board footprint just slightly bigger than that of a regular RJ45 connector. The EM202 is upward compatible with Tibbo's EM100 Ethernet Module and is programmable using Basic.

The second was the MIPS32® 34K™ family from MIPS Technologies, which is a revolutionary implementation of the MIPS® MT ASE designed to exploit multi-threading in embedded applications. Processing multiple software threads in parallel, 34K cores mask the effect of memory latency to deliver significant gains in system performance and cost savings, with a very modest increase in die size. The 34K core family also meets the real-time requirements of embedded applications by giving users the ability to allocate dedicated processing bandwidth to real-time tasks.

Finally, Apacer Technology showed off its CompactFlash II with 8 Gb capacity, ATA Flash Drive II offering 32 Gb capacity, and ATA Disk Chip II series with capacities ranging from 32 Mb to 4 Gb in size.

THEIR DAY HAS COME

Hey, the new $100 laptops are here, the new $100 laptops are here. Well, not quite. The One Laptop Per Child program founded by Nicholas Negroponte and the Massachusetts Institute of Technology's Media Lab is ready for its first "test" deployment.

Around 500 laptops will be sent to school children in Thailand for evaluation during October and November 2006. If this test run is successful, Thailand has agreed to purchase one million of these computers.

An additional four million to six million laptops have been tentatively scheduled to be sent to Nigeria, Brazil, and Argentina in 2007.

You can learn more about this program at **laptop.org**. **NV**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BY PETER BEST

THE DISH ON DHCP

DYNAMIC HOST CONFIGURATION PROTOCOL, OR DHCP, is easily understood by most folks as long as you don't start talking about the code behind it. When you've finished reading this DHCP spin of Design Cycle, you'll be able to converse with the best of them about DHCP and how it works under the hood of a microcontroller.

The DHCP C source code we will create is targeted for the Frame Thrower II from EDTP Electronics, Inc., which is based on the PIC18F8722 and the new Microchip ENC28J60 Ethernet IC. However, you can easily port the DHCP C source offered up in this column to most any microcontroller/Ethernet engine combination. There is no reason why the code we produce in the course of this Design Cycle will not work on an RTL8019AS or CS8900 Ethernet engine IC.

The DHCP concepts I'll bring into view can be used to produce source code for other programming languages, as well. The reason for this is that DHCP mechanics and our soon-to-be-developed DHCP C code are based on standards defined in RFC 2131. This standardization via RFC (Request For Comments) allows DHCP algorithms to interoperate on all types of computing platforms. Plus, the source code used to feed my HI-TECH PICC-18 C compiler is easy to understand and port.

This is going to be fun! So, let's get started by talking about the basics of DHCP.

WHAT IS DHCP?

If you were to ask the average personal computer user what DHCP was, most of them would return a blank stare. Ask an embedded engineer or serious electronic hobbyist to define DHCP and you'll probably get the answer, "That's how my box gets its IP address." In reality, DHCP provides quite a bit more information than an IP address to the requestor.

DHCP is designed to provide a means of passing configuration information to hosts on a TCP/IP network. DHCP is actually an extension of the Bootstrap Protocol, which you may know as BOOTP. BOOTP is simply a transport mechanism for various types of configuration information. If you've ever worked with diskless network hosts, you've probably been exposed to BOOTP.

The automatic allocation of reusable network addresses is one of the enhancements to BOOTP that DHCP brings to the table. The other major difference between BOOTP and DHCP is that DHCP allows the client to acquire all of the IP configuration information it needs in order to operate. Thus, the bottom line is that DHCP is designed to supply DHCP clients with enough configuration information to allow the clients to exchange packets with any other host or hosts on the Internet.

Note that I called the recipient of DHCP-delivered network parameters a client. The host that runs the DHCP code that is responsible for delivering networking parameters to the client is called the server. For our discussion, the Frame Thrower II is the client and an off-the-shelf Linksys Broadband Router is the DHCP server.

DHCP information is passed between servers and clients in the form of messages like the one depicted in Figure 1. The key to writing our DHCP C code is obtaining an understanding of the bits and bytes that make up a DHCP message and how to apply and interpret them. So, with that thought, let's break down each of the DHCP fields, beginning with the DHCP message op field.

The op field consists of a single octet (that's networkese for byte) that contains the DHCP message's op code or message type. For instance, a BOOTREQUEST is represented by a value of 1 and a BOOTREPLY is denoted by a value of 2 in the op field. The use of the op field will become second nature after you see it in the DHCP message captures, which we will look at in a moment.

If you swizzle back through the TCP/IP stack code I gave you previously and examine the ARP (Address Resolution Protocol) hardware type field, you will find that a value of 1 represents 10 Mb Ethernet. Well, the same holds true for the single octet htype (hardware address type) field in the DHCP message. The EDTP Frame Thrower II is a 10 Mb Ethernet device. So, our entry in this field as far as the Frame Thrower II is concerned will always be 1. There are 27 other

choices that can be inserted into the htype field, ranging from Experimental Ethernet (2) to HIPARP (28).

Recall that the hardware or MAC address has been six octets in length in our past UDP and TCP/IP discussions. The DHCP hlen field will contain a value of 6 to represent the length of our 10 Mb Ethernet hardware address.

We won't use the hops field as it is used by relay agents involved in a remote boot process. So, as the Frame Thrower II is not a relay agent and we have to hop to other routers or networks, we will set this field to zero.

Since there is a possibility of multiple servers offering DHCP services to a client, there is a need to differentiate servers from the client's point-of-view. The xid field is a random number chosen by the client that it uses to associate a particular DHCP message with a particular DHCP server. The xid field is four octets in length. Another field that is totally controlled by the client is the secs field, which is filled with seconds that have elapsed since the client initiated a boot request. If all goes well, we won't have to populate and keep up with the secs field.

We don't have to worry much about the DHCP flags field. Right now, all we need to do is make sure that the value of the flags field is 0x8000. The only bit that is set is the BROADCAST flag bit. The remaining bits are reserved for future use and must be set to zero.

Before we identify the use of the ciaddr (client IP address), let's put some definitions on terms associated with the ciaddr. The four octet ciaddr field is populated by the client and will contain a client-assigned IP address. However, the only situations in which the ciaddr is touched by the client are during a RENEW, BOUND, or REBINDING operation.

A RENEW operation requests a renewal of the current IP address lease from the DHCP server. A lease, in this case, is the time a client can use a reusable IP address issued to it by a DHCP server. So, before a lease expires, the client should attempt to renew the lease if the client wishes to remain active on the current network.

When a lease is involved with the DHCP transaction, the IP address is dynamically allocated by the DHCP server. If the client wishes to leave the network before its lease expires, the DHCP server will recover the IP address that was issued to the disconnected client for reallocation to a future requesting client. When a lease is not part of the DHCP transaction, the allocation of the IP address is termed automatic.

Automatic allocation assigns a permanent IP address to the requesting client. If automatic allocation is employed, when the client leaves the network, the disconnected client's IP address is not recovered by the DHCP server for allocation to a future client. DHCP can also be used in the manual allocation mode.

In manual allocation mode, the network programmer assigns an IP address to a client and simply uses the DHCP message mechanism to transmit the predetermined IP address and other pertinent network information to the desired client.

Being in the state of acceptance of network parameters — which should include an IP address — from a DHCP server is a definition of the BOUND condition. REBINDING is the process of gathering binding information to determine if a client will choose to be bound to a particular DHCP server. Everything that has to do with binding is handled by the DHCP server.

In addition to requiring the client to be in either a RENEW, a BOUND, or a REBINDING state, the use of the ciaddr field also requires that the client be able to respond to an ARP request. If ARP is a foreign word to you, fret not as I briefly covered ARP in the August '06 Design Cycle column.

Once the client puts out the word that it is in need of an IP address, the responding DHCP server will offer an IP address to the client in the yiaddr field. The yiaddr field is four octets in length and you can easily remember what it is for as the y stands for "your."

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     op (1)    |   htype (1)   |   hlen (1)    |   hops (1)    |
+---------------+---------------+---------------+---------------+
|                            xid (4)                            |
+-------------------------------+-------------------------------+
|           secs (2)            |           flags (2)           |
+-------------------------------+-------------------------------+
|                          ciaddr  (4)                          |
+---------------------------------------------------------------+
|                          yiaddr  (4)                          |
+---------------------------------------------------------------+
|                          siaddr  (4)                          |
+---------------------------------------------------------------+
|                          giaddr  (4)                          |
+---------------------------------------------------------------+
|                                                               |
|                          chaddr  (16)                         |
|                                                               |
|                                                               |
+---------------------------------------------------------------+
|                                                               |
|                          sname   (64)                         |
+---------------------------------------------------------------+
|                                                               |
|                          file    (128)                        |
+---------------------------------------------------------------+
|                                                               |
|                          options (variable)                   |
+---------------------------------------------------------------+
```

■ FIGURE 1. This jumble of bit fields will become clear to you as we walk through each of them one by one, bit by bit. The numbers in parenthesis represent the number of octets in the message field.

Thus, the yiaddr field contains "your IP address."

DHCP is designed to be totally compatible with BOOTP relay agents. The reason for this is that you don't want to have to put a DHCP server on every subnet. Since DHCP plays hand-in-hand with BOOTP, BOOTP relay agents are able to deliver DHCP messages across networks.

The siaddr field is used in the bootstrap process. Recall that I mentioned diskless hosts earlier. A diskless host must have a means of getting the information needed to boot onto a network from a network server as there are no spinning data repositories containing network information within the diskless host. Well, the siaddr (server IP address) field holds the address of the next server to use in such a bootstrap situation.

You will see the siaddr field populated by the DHCP server in DHCP offer (DHCPOFFER) and acknowledge (DHCPACK) messages when a network boot situation is in play. (Rest assured that I'll expose what's behind DHCPOFFER and DHCPACK messages down the road, so don't worry and read on.)

The giaddr (gateway IP address) field contains the relay agent's IP address that the client is booting from. Since IP addresses are involved in their content, the siaddr and giaddr fields are both four octets in length.

Within the DHCP message, we tell the world how many octets our hardware address contains inside the hlen field. In our instance, the length of the hardware (MAC) address is six octets. Although the chaddr (client hardware address) field contains 16 octets, the client only needs to fill in as many octets as are required. For instance, the Frame Thrower II MAC address is six octets in length and only those six octets will be placed into the chaddr field by the client.

The longest DHCP message fields in terms of octets are the sname (server host name) and file (boot file name) fields. The sname field is a 64-octet null-terminated (0x00) string. The actual fully qualified directory/path is placed into the 128-octet file field during a DHCP offer (DHCPOFFER). The file field is also formatted as a null-terminated string. The file and sname fields are normally used in a network boot situation.

The options field is variable in length and contains parameters that are defined in RFC 2132. When we examine an actual DHCP message, you will definitely be able to find and identify the End option, which is 0xFF (255). Other options include the client subnet mask option (1) and the router option (3).

When a client is in the request mode, the option variables are included in the options field. The DHCP message that is returned to the client contains the option parameters plus the information associated with the requested option embedded within the option field. The options field can be a maximum of 312 octets in length, which requires us to make sure we can accept a DHCP message as long as 576 octets in length.

Okay, now you know what's inside a DHCP message. Let's move on and look at what happens when we stuff certain values into the fields of a DHCP message.

DHCPDISCOVER

The very first thing a client does DHCP-wise is to broadcast a DHCPDISCOVER message. The purpose of the client broadcast is to "discover" and locate DHCP servers on the network in which it wants to participate. I've captured a full set of DHCP transactions to illustrate how

```
IP: ----- IP Header -----
  IP:
  IP: Version = 4, header length = 20 bytes
  IP: DiffServ Field  = 00
  IP:       0000 00.. = DSCP - 0 , Best Effort
  IP:       .... ..00 = ECT - Transport protocol will not participate in ECN
  IP: Total length    = 276 bytes
  IP: Identification  = 1
  IP: Flags           = 0X
  IP:       .0.. .... = may fragment
  IP:       ..0. .... = last fragment
  IP: Fragment offset = 0 bytes
  IP: Time to live    = 100 seconds/hops
  IP: Protocol        = 17 (UDP)
  IP: Header checksum = 55D9 (correct)
  IP: Source address      = [0.0.0.0]
  IP: Destination address = [255.255.255.255]
  IP: No options
  IP:
UDP: ----- UDP Header -----
  UDP:
  UDP: Source port      =    68 (Bootpc/DHCP)
  UDP: Destination port =    67 (Bootps/DHCP)
  UDP: Length           = 256
  UDP: No checksum
  UDP: [248 byte(s) of data]
  UDP:
00000000: ff ff ff ff ff ff 00 04 a3 00 00 00 08 00 45 00 ÿÿÿÿÿÿ..£.....E.
00000010: 01 14 00 01 00 00 64 11 55 d9 00 00 00 00 ff ff ......d.UÙ....ÿÿ
00000020: ff ff 00 44 00 43 01 00 00 00 01 01 06 00 12 23 ÿÿ.D.C.........#
00000030: 34 56 00 00 80 00 00 00 00 00 00 00 00 00 00 00 4V..............
00000040: 00 00 00 00 00 00 00 04 a3 00 00 00 00 00 00 00 ........£.......
00000050: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000060: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000070: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000080: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000090: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000a0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000b0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000c0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000d0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000e0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000f0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000100: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000110: 00 00 00 00 00 00 63 82 53 63 35 01 01 37 02 01 ......c‚Sc5..7..
00000120: 03 ff                                           .ÿ
```

■ FIGURE 2. This is the IP and UDP header portion of a DHCPDISCOVER message. All DHCP messages are carried within the data area of a UDP datagram. Note that the sniffer has labeled the UDP Source and Destination Ports as Bootpc/DHCP (c for client) and Bootps/DHCP (server). Note also that the client has stuffed 0.0.0.0 into the source IP address field of the IP header as it has no assigned IP address at this time.

```
DHCP: ----- DHCP Header -----
  DHCP:
  DHCP: Boot record type          = 1 (Request)
  DHCP: Hardware address type     = 1 (10Mb Ethernet)
  DHCP: Hardware address length = 6 bytes
  DHCP:
  DHCP: Hops                      = 0
  DHCP: Transaction id            = 12233456
  DHCP: Elapsed boot time         = 0 seconds
  DHCP: Flags                     = 8000
  DHCP:     1... .... .... .... = Broadcast IP datagrams
  DHCP: Client self-assigned IP address    = [0.0.0.0]
  DHCP: Client IP address                  = [0.0.0.0]
  DHCP: Next Server to use in bootstrap    = [0.0.0.0]
  DHCP: Relay Agent                        = [0.0.0.0]
  DHCP: Client hardware address            = uChip 000000
  DHCP:
  DHCP: Host name       = "
  DHCP: Boot file name = "
  DHCP:
  DHCP: Vendor Information tag = 63825363
  DHCP: Message Type            = 1 (DHCP Discover)
  DHCP: Parameter Request List: 2 entries
  DHCP: Option   Type     = 1 (Client's subnet mask)
  DHCP: Option   Type     = 3 (Routers on the client's subnet)
  DHCP:
  DHCP: End of Options    = 255
```

■ FIGURE 3. Here's a sniffer decode of the DHCP portion of a DHCP DISCOVER message. The zeros in the IP address fields indicate that the client has not yet obtained an IP address from the server. In addition to an IP address, the client has requested a subnet mask value and the IP address of all other routers on the network.

DHCP messages work.

The hex dump you see in Figure 2 is a byte view of a complete DHCPDISCOVER message. The first 12 bytes are destination and source MAC addresses. The 0x0800 byte values indicate an IP packet is the payload of this message.

Work your way through the sniffer decode area of Figure 2. You'll see that DHCP messages ride inside the data area of a UDP datagram, which is riding in the data area of an IP datagram. In the Figure 2 capture, the UDP header informs us that there are 248 bytes of DHCP message inside the UDP datagram.

One of the important points to note in Figure 2 is the designations of the UDP source and destination ports. The sniffer has been kind enough to label the UDP ports for us as client (Bootpc/DHCP-port 68) and server (Bootps/DHCP-port 67). These port addresses are constants and are considered well-known port addresses. Also note that the client does not have an assigned IP address at this time. Thus, the 0.0.0.0 entry in the IP header's IP address field.

The slew of 0xFF (255 decimal) bytes in the capture's destination MAC and IP addresses should scream "broadcast message" to you. If you associate Figure 2's sniffer decode with the bytes of hex dump, the IP header is 20 bytes long and begins at offset 0x0E, ending at offset 0x21. The UDP header is found beginning at offset 0x22 and runs for eight bytes, ending at offset 0x29.

The data beginning at offset 0x2A of Figure 2 is the beginning of the DHCPDISCOVER message. The sniffer has broken down all of the fields for us in Figure 3. You can use the raw DHCP message layout in Figure 1 and the sniffer decode in Figure 3 to match up the words to bytes in the hex dump portion of Figure 2. I'm not going to insult your intelligence as I'm sure that you can relate what you see in Figure 3 to everything about DHCP messages we've discussed thus far. I will, however, elaborate on things we haven't discussed such as the Vendor Information tag, which is called the "magic cookie."

The magic cookie is always found in the first four octets of the vendor information field and is used to identify the mode in which the succeeding data is to be interpreted. The bytes you see in our magic cookie will be

```
DHCP: ----- DHCP Header -----
  DHCP:
  DHCP: Boot record type          = 2 (Reply  )
  DHCP: Hardware address type     = 1 (10Mb Ethernet)
  DHCP: Hardware address length = 6 bytes
  DHCP:
  DHCP: Hops                      = 0
  DHCP: Transaction id            = 12233456
  DHCP: Elapsed boot time         = 0 seconds
  DHCP: Flags                     = 8000
  DHCP:     1... .... .... .... = Broadcast IP datagrams
  DHCP: Client self-assigned IP address    = [0.0.0.0]
  DHCP: Client IP address                  = [192.168.1.103]
  DHCP: Next Server to use in bootstrap    = [0.0.0.0]
  DHCP: Relay Agent                        = [0.0.0.0]
  DHCP: Client hardware address            = uChip 000000
  DHCP:
  DHCP: Host name       = "
  DHCP: Boot file name = "
  DHCP:
  DHCP: Vendor Information tag = 63825363
  DHCP: Message Type            = 2 (DHCP Offer)
  DHCP: Server IP address       = [192.168.1.1]
  DHCP: Subnet Mask                  = [255.255.255.0]
  DHCP: Request IP address lease time = 86400 (seconds)
  DHCP: Router Option
  DHCP: Length = 4
  DHCP: Gateway address                  = [192.168.1.1]
  DHCP: Domain Name Server address Option
  DHCP: Length = 4
  DHCP: Domain Name Server address  = [192.168.1.1]
  DHCP: Interface MTU                    = 1492
00000000: ff ff ff ff ff ff 00 13 10 d4 c6 cc 08 00 45 00 ÿÿÿÿÿÿ...ÔÆÌ..E.
00000010: 02 40 77 ac 00 00 40 11 3f 58 c0 a8 01 01 ff ff .@w¬..@.?XÀ¨..ÿÿ
00000020: ff ff 00 43 00 44 02 2c ac c8 02 01 06 00 12 23 ÿÿ.C.D.,¬È.....#
00000030: 34 56 00 00 80 00 00 00 00 00 c0 a8 01 67 00 00 4V........À¨.g..
00000040: 00 00 00 00 00 00 00 04 a3 00 00 00 00 00 00 00 ........£.......
00000050: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000060: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000070: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000080: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000090: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000a0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000b0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000c0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000d0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000e0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000f0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000100: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000110: 00 00 00 00 00 00 63 82 53 63 35 01 02 36 04 c0 ......c.Sc5..6.À
00000120: a8 01 01 01 04 ff ff ff 00 33 04 00 01 51 80 03 ¨....ÿÿÿ.3...Q..
00000130: 04 c0 a8 01 01 06 04 c0 a8 01 01 1a 02 05 d4 [illegible] .À¨....À¨.....Ô.
00000140: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
```

■ FIGURE 4. This DHCP message comes from the Linksys router on my two-host network. Note that in addition to an offer of an IP address, the client has been given the subnet mask value and the IP address of the Linksys router.

constant throughout our DHCP discussion. That's all you need to know for now about the magic cookie.

The Message Type fields that follow the Vendor Information tag are interpreted as follows. The 0x35 (53 decimal) is the option identifier that signifies the beginning of a string of octets defining the DHCP message type. The 0x01 following the option code is the length of the option parameter, which is one octet, in this case. The next 0x01 is the actual message type which, according to RFC 2132, is a DHCPDISCOVER.

The Parameter Request List is identified as option identifier 0x37 (55 decimal). Like the DHCP message type option identifier, the Parameter Request List option identifier is followed by a length field, which is followed by the option codes field. In our capture, the client is requesting a subnet mask value and information about other routers on the subnet.

The DHCPDISCOVER message we just examined was broadcast onto my little two-host network. Now let's see what we get.

DHCPOFFER

The Linksys router returned the DHCP reply message (DHCPOFFER message) you see in hex form and sniffer decode form in Figure 4. What you don't see in Figure 4 is the IP header and UDP header information I provided in Figure 2. The only significant change that occurred in the IP header area was in the IP header source address field, which reflects that the DHCPOFFER message originated at 192.168.1.1 (the Linksys router).

The DHCPOFFER message is also a broadcast message as the requesting client still does not have an assigned IP address at this time. As for the UDP header information you don't see in Figure 4, I only want to point out the length of the DHCPOFFER message, which is 548 bytes.

In Figure 4, the server (Linksys router) is offering the Frame Thrower II client an IP address of 192.168.1.103 in the Client IP address field. The rest of the information we are really interested in follows the magic cookie. We now know that the Linksys router's IP address is 192.168.1.1 and the subnet mask of the network controlled by the Linksys router is 255.255.255.0.

The Linksys router is the only router on the network and is also identified as the gateway and the Domain Name Server. Recall that the client's DHCPDISCOVER message requested client subnet and router information. The Linksys router has also told us its maximum message size is 1,492 bytes before fragmentation is employed. If the client accepts this offer, the lease time for the IP address and all of the associated network information in the offer is 24 hours (86,400 seconds).

NOW WHAT??

I can tell you that the client will accept the offer by assembling and transmitting a DCHPREQUEST message, which is shown in hex format and sniffer decode format in Figure 5. We've covered the format of a DHCP message. So, all I should have to tell you is that following the four octets that form the magic cookie (0x63, 0x82, 0x53, 0x63), 0x35 begins the message type option, 0x36 begins the server identifier option, 0x37 begins the parameter request list, and 0x32 begins the requested IP address option. Now that you have the option landmarks, you should be able to match up the hex bytes to the sniffer breakdown. I'm positive you know what the final 0xFF in the options field is for.

Assuming things fall into place as designed, the final step of the DHCP process involves the server sending a DHCPACK message, which you can

```
DHCP: Boot record type        = 1 (Request)
DHCP: Hardware address type   = 1 (10Mb Ethernet)
DHCP: Hardware address length = 6 bytes
DHCP:
DHCP: Hops                    = 0
DHCP: Transaction id          = 12233456
DHCP: Elapsed boot time       = 0 seconds
DHCP: Flags                   = 8000
DHCP:     1... .... .... .... = Broadcast IP datagrams
DHCP: Client self-assigned IP address   = [0.0.0.0]
DHCP: Client IP address                 = [0.0.0.0]
DHCP: Next Server to use in bootstrap   = [0.0.0.0]
DHCP: Relay Agent                       = [0.0.0.0]
DHCP: Client hardware address           = uChip 000000
DHCP:
DHCP: Host name      = ""
DHCP: Boot file name = ""
DHCP:
DHCP: Vendor Information tag = 63825363
DHCP: Message Type            = 3 (DHCP Request)
DHCP: Server IP address       = [192.168.1.1]
DHCP: Parameter Request List: 2 entries
DHCP: Option   Type     = 1 (Client's subnet mask)
DHCP: Option   Type     = 3 (Routers on the client's subnet)
DHCP: Request specific IP address = [192.168.1.103]
DHCP:
DHCP: End of Options    = 255
00000000: ff ff ff ff ff ff 00 04 a3 00 00 00 08 00 45 00 ÿÿÿÿÿÿ..£.....E.
00000010: 01 20 00 02 00 00 64 11 55 cc 00 00 00 00 ff ff ......d.UÌ....ÿÿ
00000020: ff ff 00 44 00 43 01 0c 00 00 01 01 06 00 12 23 ÿÿ.D.C.........#
00000030: 34 56 00 00 80 00 00 00 00 00 00 00 00 00 00 00 4V..............
00000040: 00 00 00 00 00 00 00 04 a3 00 00 00 00 00 00 00 ........£.......
00000050: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000060: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000070: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000080: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000090: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000a0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000b0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000c0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000d0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000e0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000f0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000100: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000110: 00 00 00 00 00 00 63 82 53 63 35 01 03 36 04 c0 ......c▮Sc5..6.À
00000120: a8 01 01 37 02 01 03 32 04 c0 a8 01 67 ff       "..7...2.À".gÿ
```

■ FIGURE 5. The client has decided to go with this offer from the Linksys router. Note that the client has also requested subnet mask and router information in this request message.

```
DHCP: ----- DHCP Header -----
 DHCP:
 DHCP: Boot record type          = 2 (Reply  )
 DHCP: Hardware address type     = 1 (10Mb Ethernet)
 DHCP: Hardware address length = 6 bytes
 DHCP:
 DHCP: Hops                      = 0
 DHCP: Transaction id            = 12233456
 DHCP: Elapsed boot time         = 0 seconds
 DHCP: Flags                     = 8000
 DHCP:    1... ....  .... .... = Broadcast IP datagrams
 DHCP: Client self-assigned IP address   = [0.0.0.0]
 DHCP: Client IP address                 = [192.168.1.103]
 DHCP: Next Server to use in bootstrap   = [0.0.0.0]
 DHCP: Relay Agent                       = [0.0.0.0]
 DHCP: Client hardware address           = uChip 000000
 DHCP:
 DHCP: Host name      = "
 DHCP: Boot file name = "
 DHCP:
 DHCP: Vendor Information tag = 63825363
 DHCP: Message Type              = 5 (DHCP Ack)
 DHCP: Server IP address         = [192.168.1.1]
 DHCP: Subnet Mask                    = [255.255.255.0]
 DHCP: Request IP address lease time = 86400 (seconds)
 DHCP: Router Option
 DHCP: Length = 4
 DHCP: Gateway address                = [192.168.1.1]
 DHCP: Domain Name Server address Option
 DHCP: Length = 4
 DHCP: Domain Name Server address  = [192.168.1.1]
 DHCP: Interface MTU                  = 1492
00000000: ff ff ff ff ff ff 00 13 10 d4 c6 cc 08 00 45 00 ÿÿÿÿÿÿ...ÖÆÌ..E.
00000010: 02 40 77 ad 00 00 40 11 3f 57 c0 a8 01 01 ff ff .@w-..@.?WÀ"..ÿÿ
00000020: ff ff 00 43 00 44 02 2c a9 c8 02 01 06 00 12 23 ÿÿ.C.D.,©È.....#
00000030: 34 56 00 00 80 00 00 00 00 00 c0 a8 01 67 00 00 4V........À".g..
00000040: 00 00 00 00 00 00 00 04 a3 00 00 00 00 00 00 00 ........£.......
00000050: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000060: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000070: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000080: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000090: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000a0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000b0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000c0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000d0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000e0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
000000f0: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000100: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
00000110: 00 00 00 00 00 00 63 82 53 63 35 01 05 36 04 c0 ......c.Sc5..6.À
00000120: a8 01 01 01 04 ff ff ff 00 33 04 00 01 51 80 03 "....ÿÿÿ.3...Q..
00000130: 04 c0 a8 01 01 06 04 c0 a8 01 01 1a 02 05 d4 ff .À"....À"....Ôÿ
00000140: 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 ................
```

■ FIGURE 6. The server positively acknowledges the client's request for the network information. The client now has known-good network parameters in its possession and is able to use the incoming information within the acknowledgement to join the network.

see in Figure 6. The client absorbs this information and has everything it needs to join the network at this point. Right now, we just want to get the basics of DHCP under our belt.

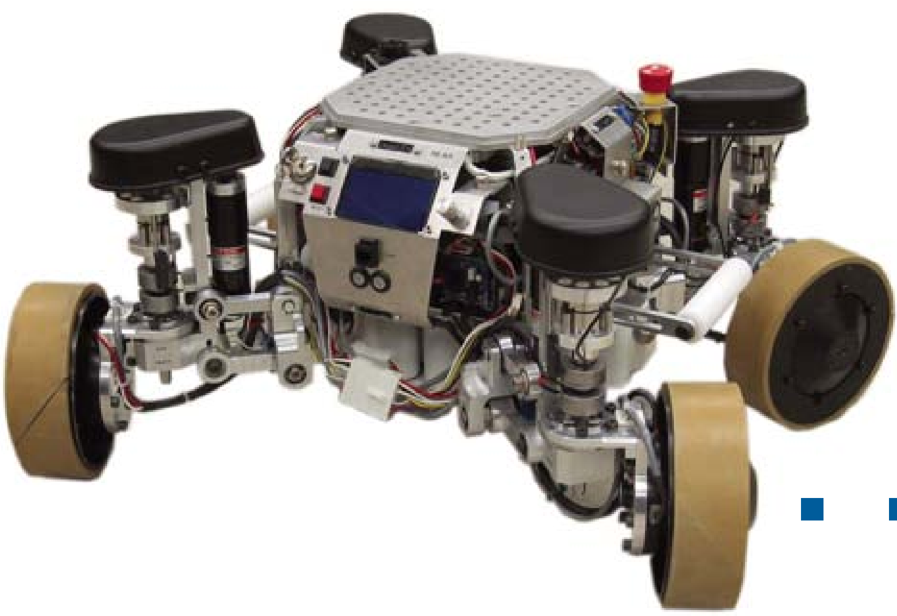
We'll tackle the possibility of a DHCPNAK (negative response) situation when we write our DHCP code.

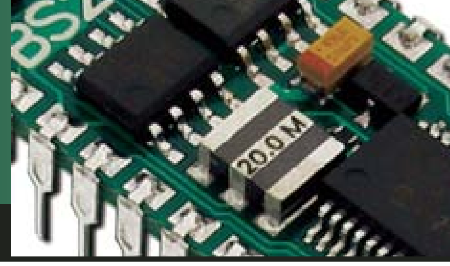
You should be able to navigate the bits and bytes of Figure 6 without any help from me. If you hit a snag, pick up the DHCP RFC documents and work your way through to your answer. It's really not that difficult to decipher the DHCP RFC language. If you need some guidance, just send me an email at peter@nerdvilla.com.

Next time, we'll match up some home-grown DHCP C code to the DHCP messages we've just examined. To be able to follow the DHCP coding, you will need to understand the mechanics of the DHCP messages. So, get on the Internet and get yourself copies of RFC 2131 and RFC 2132. Then, compare the text in the RFCs to the sniffer captures and explanations I've provided. Do that and you'll be ready to code up some DHCP messages next time as we're half way there to putting embedded DHCP into your Design Cycle. **NV**

ABOUT THE AUTHOR

■ If you'd like to contact Peter Best, send him an email at **peter@nerdvilla.com**





STAMP APPLICATIONS

PUTTING THE SPOTLIGHT ON BASIC STAMP PROJECTS, HINTS & TIPS

■ BY JON WILLIAMS

GOIN' WITH THE GLOW

I'M PRETTY SURE THAT SCOTT EDWARDS HAD NO IDEA what he was starting way back in the early '90s when he released his first serial LCD. Back then, the target customer was someone like me — a BASIC Stamp 1 user who wanted a nice display but didn't have a lot of spare I/O pins to support it. Well, as we've seen, serial LCD modules have become about as ubiquitous to electronics experimenters as the 555 timer chip. There are, however, environments that can present serious challenges to LCDs, specifically those with extremes in ambient lighting and temperature — something industrial users face every day. Enter the VFD: the vacuum tube fluorescent display.

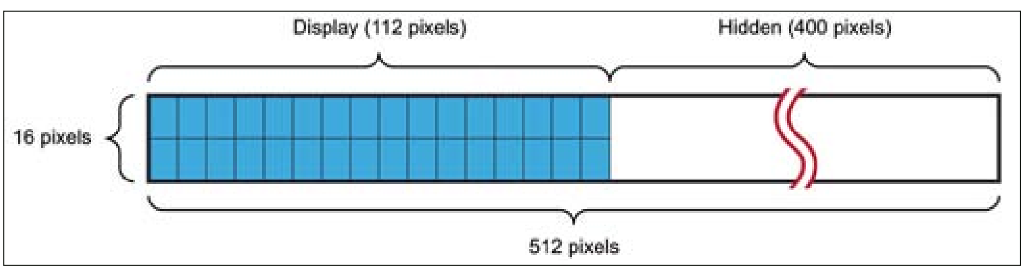
Even if you're not sure what I mean by VFD, it's a pretty good bet that you've seen them. VFDs are self-illuminating and very bright, have a striking blue-green color cast, and, on close inspection, you can see that the works are contained in a thick glass envelope. Before the explosion of LCDs, VFD displays were actually quite common in consumer devices like VCRs. In fact, when I worked in the irrigation industry, we used a VFD designed for a VCR in a golf course sprinkler controller; the elements of the display matched our requirements well, and being a VFD meant that it worked under the lighting and temperature extremes we'd encounter in outdoor use on a golf course.

The VFD that we're going to work with is the Noritake GU112X16G-7003. It's about the same size as a 2 x 16 serial LCD, albeit just a tad thicker. Connections are pretty easy: power (5 VDC, 350 mA max), a 38.4K serial connection, and ground. Do note, though, that the connections on the VFD are not compatible with standard servo extender cables, so you'll probably want to modify an off-the-shelf cable or roll your own. For our experiments, we can plug the VFD right into the breadboard of a BOE or the PDB.

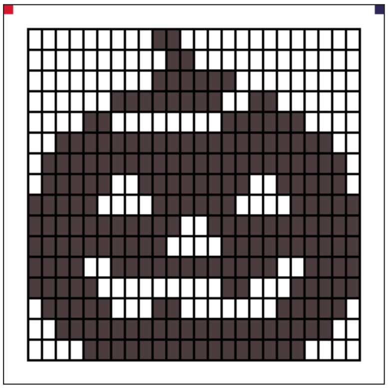
When you look over the detail specifications, you'll see that it mentions jumpers for the selection of baud rates. The default setting is 38.4K, but it can go to 115.2K if you intend to use it with an SX chip. What the Noritake documentation refers to as "jumpers" are actually blank pads that you'll need to bridge with solder if you want to select the higher speed. In most applications this probably won't be necessary.

In practice, you can treat the GU112X16G-7003 very much like a serial LCD after meeting its initial setup requirements. A key difference, however, is cursor positioning. You see, this display is inherently graphic, so the cursor positioning commands always refer to a bit when dealing with the X (horizontal) axis. This is nice as it gives us very precise positioning control, even when we're simply using the display for text. Again, that bit-level positioning is only on the X axis; the Y aspect of cursor positioning is always by row (0 or 1).

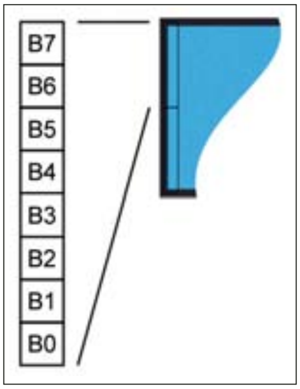
While we're on the subject of cursor positioning, let's discuss the display versus what isn't seen. Figure 1 shows this display memory. Note that 112 horizontal pixels are visible and 400 are hidden — but can be written to when the display is set to "all screen." What you'll see in practice is that the all screen mode allows the display of partial characters when they are positioned between normal character boundaries. When in "display screen" mode — where only the visible area of the screen is used — characters pushed to one edge will wrap around to the other, and will do so as whole characters. You can see this in a little demo program — called GU112x16G_ScreenMode.BS2 — that I've included in the download package available on the *Nuts & Volts* website (**www.nutsvolts.com**).



■ FIGURE 1. GU112X16G Memory Map.



■ FIGURE 2. Pumpkin bitmap.



■ FIGURE 3. Bitmapping.

MIX IT UP

Where the GU112X16G-7003 differs from VFDs that emulate LCDs is that we can mix text and graphics in the same display. Now, there is a bit of work involved for us to do this, having mostly to do with the organization of bit images in the display. And this is where our focus will be this month: getting a graphic of our choice into the display. There are times when we as technical types are called on to be a bit artistic, so tools we might not consider in our day-to-day programming chores are going to be pulled out to get the job done.

Let's say, for example, that a customer gives us a logo that they'd like displayed in the GU112X16G while the program is waiting for some sort of user entry, perhaps from an RFID reader. What do we do? Well, the first thing we'll want to do is see if the image is viable as a 112 x 16 monochromatic bitmap.

You don't need to be a graphics wizard to do this stuff, but it will be helpful if you have some experience with a program like Photoshop, Paint Shop Pro, or The Gimp. Any of these programs (and there are many others) will let us scale the image to see what it will look like in a 112 x 16 display. That's Step 1. The next step is overlaying a blank map of the display pixels that we can fill in or clear to create the actual pixel map for the GU112X16G. For this, I use a graphic called *noritake_blank.bmp* — this is actually about 8x the display size, making it a lot easier to change pixels with the fill tool. The idea is to pull your raw graphic into the project as a layer below the blank pixel map, scale it to fit the desired size of the pixel map, then set the pixel map transparency down enough so that you can see your image through it. After that, it's a matter of filling in and clearing pixels in the map layer to best match the target graphic.

The second part is critical if you want to get an accurate representation of the original image. The reason for this is something called Pixel Aspect Ratio; this is the ratio between the height and width of a pixel. On our computer monitors, this ratio is 1:1 as the pixels are square. But the GU112X16G has rectangular pixels, with an aspect closer to 3:2, that is, the pixels are taller than they are wide. What you'll find if you attempt to map square pixels is that your image will be too skinny. The pumpkin we're about to use as a demo, for example, looked more like a yellow squash when mapped as square pixels. Figure 2 shows my completed pumpkin graphic after tweaking for the PAR and using the blank template with properly shaped pixels. As you can see, the image is square, but due to the PAR, it is 24 pixels wide by 16 pixels tall.

Now that we have an image that can be mapped accurately into the display, let's look at how it's stored in the display RAM — this will affect our choice of program storage and downloading design. Figure 3 shows the arrangements of bits in one column of a graphic. Note that only eight bits are shown; if the graphic uses two rows (16 bits tall), then the organization is the same: bits run top to bottom, but the data stream to the display starts on the top row. For a 16-bit tall graphic, then, every other byte is a column on the top row of the display, and the alternate bytes are for the bottom row.

It sure would have been easier if the bits were mapped left-to-right instead of bottom-to-top, but the organization used by the GU112X16G probably makes the display internals a little more efficient since each row is exactly eight bits tall. Still, it presents a challenge for us to encode into our listing easily. After staring at the data organization for what seemed like an eternity, I came up with a workable scheme that lets us write **DATA** statements top-to-bottom to correspond with the image being displayed left-to-right.

I rotated the graphic 90 degrees counterclockwise, and then flipped it around its horizontal axis (note the registration marks in the corners of my demo graphics). Now I can map each horizontal line as an eight- or 16-bit value for the graphic. Figure 4 shows the pumpkin graphic after it has been rotated and flipped head to toe. As you can see, I also divided the graphic into four-column (nib-sized) chunks; I found this a bit easier on my eyes when transposing the pixels to 1s (filled) and 0s (not filled).

With the graphic encoded into a **DATA** table, the final step is to create a routine that will display the image at the current cursor position. To make life simpler with the GU112X16G, I coded what I felt were the most useful features into subroutines that are easy to call. Since there are two possibilities for graphic heights, there are separate routines, but they work about the same. Let's look at displaying a 16-bit tall image.

```
DL_Graphic2:
  SEROUT Sout, Baud,
          [$1F, $28, $66, $11,
           width.BYTE0, width.BYTE1, 2, 0, 1]

  FOR idx = 0 TO width*2-1 STEP 2
    READ (addr + idx), Word temp
    SEROUT Sout, Baud, [tmpHi, tmpLo]
  NEXT
  RETURN
```

As you can see, it's not terribly complicated outside the command sequence required by the VFD. The first four bytes of the serial command specify the real-time bit image display. This is followed by the width of the graphic (low byte, then high byte), the height in rows (two in this case), and a 1 for fixed image as called out in the spec. What follows this command is the column data for the image.

I chose to use the Word modifier in the **DATA** statements so that I have a single string of bits. When we do this, the BASIC Stamp compiler stores the information low-byte/high byte, so it's now out of order from the requirement of the display. What this means is that we can't read and

transmit a byte at a time. What we'll do, of course, is read it back a word at a time and then send the bytes in the correct order (first high, then low). Since we're reading word-sized values from the table, we need to toss **STEP 2** into the **FOR-NEXT** loop to maintain proper byte alignment for **READ**. It may look odd at first to multiply the width by two (for two bytes for column) and then use a step size of two but, again, we have to do this because **READ** works on byte boundaries.

An interesting thing happens when we put a 16-bit tall graphic onto the second row: only the top half of the image is displayed. Well, this can actually come in handy, and when you run the demo program, you'll see that we can make the pumpkin appear to jump up from the bottom of the display by starting it on row 1, then immediately displaying it in the same column on row 0.

The graphics demo program has another image: an eight-bit tall bat. Creating and encoding the image is identical to what we did with the pumpkin, though we only have eight bits on a line. Since the image is just one row tall, we can simplify the **FOR-NEXT** portion of the download loop as shown here.

```
DL_Graphic1:
  SEROUT Sout, Baud,
          [$1F, $28, $66, $11,
           width.BYTE0, width.BYTE1, 1, 0, 1]

  FOR idx = 0 TO width-1
    READ (addr + idx), tmpLo
    SEROUT Sout, Baud, [tmpLo]
  NEXT
  RETURN
```

Okay, let's put the graphics to use. Our main demo program (GU112x16G_Halloween.BS2) starts by resetting the VFD and changing the write mode to XOR. Remember that any bit XOR'd with itself will be zero, so writing a graphic on top of itself in this mode will cause the second write sequence to erase the first. We want to do this because the beginning of the program is going to "fly" the bat graphic across the display. Within a loop we'll display the bat graphic twice in the same position with a short delay in between; the delay creates the flight timing.

```
Main:
  GOSUB Reset_VFD
  mode = VFD_XOR
  GOSUB Set_Mode

Fly_Bat:
  addr = Bat
  width = 22
  FOR col = 0 TO 112 STEP 22
    FOR row = 1 TO 0
      GOSUB Put_Crsr
      GOSUB DL_Graphic1
      PAUSE 100
      GOSUB DL_Graphic1
      col = col + 22
    NEXT
  NEXT

  mode = VFD_NORM
  GOSUB Set_Mode
```

After the bat flies off the screen, we can display our message with simple cursor positioning and text writing.

```
col = 30
row = 0
GOSUB Put_Crsr
SEROUT Sout, Baud, ["HAPPY"]
row = 1
GOSUB Put_Crsr
SEROUT Sout, Baud, ["HALLOWEEN!"]
```

This is easy stuff — again, remember that our column positioning resolution is one pixel.

Next comes the pumpkin display. We can make it "pop up" by putting the row value into a loop, using a short delay in between to control movement timing.

```
addr = Pumpkin
width = 24
FOR row = 1 TO 0
  col = 0
  GOSUB Put_Crsr
  GOSUB DL_Graphic2
  PAUSE 50
NEXT
```

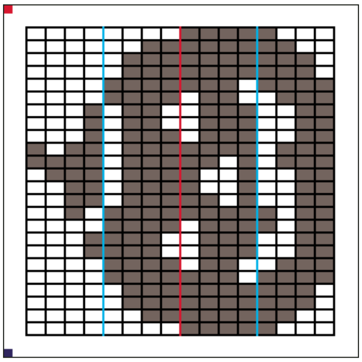
The final part of the graphic demo program gives a bit of insight into what are called "user windows." The GU112X16G has a base (default) window which encompasses the entire display, and it allows us to define up to four user windows that have individual control. What the user windows don't have is their own coordinate system; position values in the user window are taken from the underlying base window.

So, let's define a user window in the upper right-hand corner of the display.

```
SEROUT Sout, Baud,
        [$1F, $28, $77, $02, 1, 1,
         90, 0, 0, 0,
         22, 0, 1, 0]
```

Zoiks, Batman, that's complicated! Yes, I agree — but if we can get a handle on it there are benefits that allow us to generate sophisticated display actions. The first line in the output data specifies the user definition for window #1. The next line says that the upper-left corner of the window is at column 90, and on row 0. The second line says that the window in 22 pixels wide and one row (eight pixels) deep.

The window is now defined, but we have to select it before doing anything with it. This part is pretty easy.



■ FIGURE 4. Pumpkin rotated for mapping.

■ FIGURE 5. The Noritake Halloween greeting.

```
SEROUT Sout, Baud, [$1F, $28, $77, $01, 1]
```

Finally, let's paint the bat image into the window and alternately clear it to make the bat blink. This is different from using the XOR mode as before, and it demonstrates that the Display Clear command of the VFD affects only the current window.

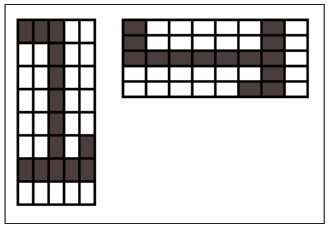
```
FOR flashes = 1 TO 5
  GOSUB Clear_Window
  PAUSE 50
  col = 90
  row = 0
  GOSUB Put_Crsr
  addr = Bat
  width = 22
  GOSUB DL_Graphic1
  PAUSE 150
NEXT
```

Notice that we actually start by clearing the window and then painting in the bat graphic. This sequence leaves the bat graphic in place at the end of the flashing loop. Figure 5 shows the final display with mixed text and graphics.

CUSTOM CHARACTERS

One of the things we all love about character LCDs is the ability to define custom characters. Well, the GU112X16G gives us that capability, as well — in fact, up to 16 characters. The difference is that we will actually map out custom characters onto the address of an existing character in the display. Now, the coolest thing, in my opinion, is that we can alternately select between a standard version of the character and our custom version of the character. We can even have both versions of a character in the display at the same time, as the enabling/disabling of custom characters only affects subsequent writes; anything already in the display is not affected. How cool is that?

The GU112X16G supports multiple character fonts, but to keep things easy, we'll stick the standard 5 x 7 bit font that will be used for most of our applications. After mapping the new character (like we did with the pumpkin and bat), we will once again rotate and flip the bit pattern so that the bits can be properly mapped into a **DATA** table (I've included my reference images in the download package). Figure 6 shows a custom digit "1" and its rotated and flipped version for mapping into **DATA** statements. The GU112X16G allows us to download more than one character at a time, but I think it's simpler to encapsulate the character downloading sequence into a subroutine like this:



■ FIGURE 6. This shows a custom character "1."

```
DL_Char:
  SEROUT Sout, Baud,
         [$1B, $26, $01, char, char, 5]
  FOR idx = 0 TO 4
    READ (addr + idx), tmpLo
    SEROUT Sout, Baud, [tmpLo]
  NEXT
  RETURN
```

Again, this is set up so that we point to the character data with *addr*, and at that location will be five bytes that define the new character shape. The variable called *char* holds the ASCII code of the character that we are redefining.

For the demo, I decided to change the decimal digits to an OCR-type font. The new characters are downloaded with a simple loop.

```
FOR char = "0" TO "9"
  addr = Digit0 + ((char-"0") * 5)
  GOSUB DL_Char
NEXT
```

Now to use the custom characters, we have to enable them — that's a pretty simple command sequence.

```
Enable_Custom:
  SEROUT Sout, Baud, [$1B, $25, 1]
  RETURN
```

There's a similar subroutine for disabling the custom characters.

When the demo is running, it doesn't look like it's doing anything but, in fact, it's constantly updating the display, switching between the internal digit maps and our custom character maps.

```
DO
  col = 0
  FOR row = 0 TO 1
    GOSUB Put_Crsr
    IF (row = 1) THEN
      GOSUB Enable_Custom
    ELSE
      GOSUB Disable_Custom
    ENDIF
    SEROUT Sout, Baud, ["0123456789"]
  NEXT
  PAUSE 250
LOOP
```

While the column remains fixed at zero, we loop through rows zero and one, writing the string of characters. When we're on the top row, the internal characters are used (custom characters are disabled); when we're on the bottom row, we use the

custom ones. Look at the display — it contains both versions (standard and custom) of the decimal digits at the same time.

CHECK THE SPECS

I will admit that getting the full specifications for the GU112X16G display was a bit of a challenge. I had to make five calls to five different Noritake engineers. Finally, with the last guy, I detected a bit of Japanese accent so I wowed him with my staggering Japanese vocabulary (yes, I'm being facetious — I know enough to explain to a native speaker that I don't quite understand what they're saying). This made him laugh and he sent the full specification. I've included this in the download package, as well, so please have a look because there are many more features of the GU112X16G that are worth exploring.

My old pals at Parallax have started releasing more app notes on the GU112X16G, so do check their website for anything new. Between what we've done here, the specs, and the Parallax docs and app notes, you should be able to push the GU112X16G to do anything it is capable of doing.

So, until next time, have a safe and happy Halloween — and, as always, Happy Stamping! **NV**

RESOURCES

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■ BY LOUIS E. FRENZEL W5LEF

THE ULTIMATE WIRELESS HOBBYIST

How the Hobby Has Evolved

Wireless has been a hobby for well over 100 years. And looking back, I have actually been a wireless hobbyist for most of my natural life. I have tried almost all aspects of this hobby and have witnessed an amazing evolution along the way.

Technological and social changes have certainly modified the way we approach radio as a hobby. If you haven't been paying attention or participating in this hobby, it may surprise you to find out just what it is all about today. Here is a look at the radio hobby today and how you, as an electronic enthusiast, can join in the fun.

WIRELESS HOBBYIST ... WHAT'S THAT?

A wireless hobbyist is someone that fools around with radio as a spare time endeavor. It is a person who is interested in any aspect of radio or wireless and spends time and money on learning more about it and experimenting with it. By this definition, you may already be one. If not, after reading this you just may want to get started. In any case, just what comes into your mind when you hear the term wireless hobbyist? You can stereotype all you want but I suspect you do not know the half of it. Take a minute and list what you think are the wireless hobbies.

Surprise ... wireless as a hobby is bigger than you thought. It is not just some guy in a scroungy basement or garage soldering together a one transistor radio, a guy installing a CB radio in his truck, or a ham putting up a new antenna, although those certainly fit. What makes the hobby so big these days is that it has actually expanded thanks to technology developments. I suspect many who are wireless hobbyists do not think of themselves as that.

The wireless hobbyist used to be primarily one who built his or her own wireless gear, then used it to listen or to transmit if that person had a license. Today, there is far less building and more listening and transmitting. The hams have a name for people who do this ... appliance operators. It used to be a derogatory term meaning those who did not build their own gear were not real hams. Today, appliance operators are the norm. Wireless hobbyists, hams, or whatever, buy rather than build their equipment today, then spend the time on operating or using it instead.

Today's hobbyist operates at a higher level. Instead of working with resistors, coils, capacitors, transistors, ICs, and other components, the hobbyist *applies* the end equipment. Hobbyists work at what is probably best described as the system level where multiple pieces of equipment are involved.

The main reason for the system level emphasis is simply the complexity of the equipment and the fact that so much of it is contained in just a few ICs. It is far more difficult to build because of surface-mount components and ICs so small you can hardly see them, much less solder them into place. It is not impossible, of course, but just far more difficult and far more expensive. It is much cheaper to just buy finished equipment and avoid the frustration and failure of working with impossibly small parts.

That is not to say we don't have hobbyists who still build their own gear. There just aren't as many of these types as there used to be and those who do this tend to also be design engineers or techs who work with wireless gear in their jobs. They know how to do it. So what is the wireless hobby if there is less building going on? Here is a summary of what people are doing now.

AMATEUR RADIO

This is probably the oldest wireless hobby activity. In fact, the hobbyists played a major role in radio's early development. It started during the spark gap age but really blossomed when the first vacuum tubes came along. It is still going strong with about three million hams worldwide and roughly 670,000 in the US. You have to get a Federal Communications Commission (FCC) license to be a ham. It is not difficult, but only the most dedicated are willing to invest the time to learn what is needed to pass the exams.

You still see hams building simple low power (QRP) transmitters and receivers and some accessories, but for the most part, hams buy sophisticated DSP transceivers worth up to several thousand bucks each. They rag

chew (just talk), search for distance hams (DXing), and work contests. They participate in emergency situations like hurricanes. Their experimentation involves multiple pieces of equipment, for example, connecting the transceiver to a high power amplifier.

There is probably more experimentation with antennas than anything else. Antenna tuners, SWR meters, different coax, and so on. The UHF and microwave worlds give lots of opportunity to play around with exotic equipment and antennas to break distance records. Repeaters are still very popular.

Another aspect of the hobby is trying out new modes like TV or digital packet radio (like PSK31 and others) where the radio is connected to a PC for I/O. Ham satellite monitoring and communications is also popular. The possibilities are not endless but they are extensive enough to keep you occupied and broke for a lifetime.

If you love radio and want a way to do it all, get a license. For more info, go to the American Radio Relay League's (ARRL) website at **www.arrl.org**. The ARRL's *QST* and *QEX* magazines are excellent resources, as is *CQ Magazine* (**www.cq-amateur-radio.com**).

CB AND FRS

The citizens band (CB) radio craze started in the 1960s. It really boomed in the 1970s. Practically everyone had a CB in their car. Truckers used it and still do, especially in rural areas. Since it uses the 27 MHz band, working others at long distances was possible, although not sanctioned.

If you just like to talk, test out different antennas, and fill the need of the security a CB brings, this is still a good hobby to get into.

Family radio service (FRS) came about in the 1990s. It authorized unlicensed two-way radio use in the 462-467 MHz band. Cheap two-way FRS radios have been available for years and families use them for communications in malls, hiking, and working around the house. The distance is limited by the environment but it can be up to a mile or so if the path is clear. Experimenting with range is one aspect of this hobby.

MONITORING

This is a huge hobby with many facets. Monitoring means listening. And, wow, there is a lot to listen to. Most of it involves shortwave (SW) listening in the 3 to 30 MHz range. There are thousands of international SW broadcasts around the world to check out and lots of slick high tech radios that address this space. There's also the scanner crowd. Scanners operate in the VHF, UHF, and microwave regions, so monitoring is of public safety (police, fire, etc.) and public service radio. You can also monitor aircraft, marine, and military transmissions.

Broadcast radio is also popular. Listening to AM radio at night is a real surprise if you have a big antenna. You can hear stations all across the US. Seeking long-range FM radio stations is another aspect of this. Most FM is local, but with a high antenna, you can get stations from far away. TV monitoring can also be fun. Most people get TV via cable these days, but you can still have fun with a high antenna on a rotor trying to log TV stations from distant locations.

Satellite TV and satellite radio can also be considered when experimenting with antennas. To learn more about the many antennas that will make or break your listening, check out *Popular Communications Magazine* (**www.personal-communications.com**) and *Monitoring Times Magazine* (**www.monitoringtimes.com**).

COMPUTERS

Wireless is widely used with computers. The big one is a wireless LAN. Using the Wi-Fi transceivers working in the 2.4 GHz band makes it possible to log into the Internet from work and at thousands of public access points in hotels, airports, coffee shops, and convention centers. Many people now have a home network to connect to the Internet with.

Installing your own wireless access point is pretty straightforward. Hackers will play around with long range antennas and higher power to create mesh networks and find access points far away. One of the most popular gadgets is the so-called Pringles can antenna. Do a Google or Yahoo! search if you are interested.

There are also wireless peripherals. You can use Bluetooth to connect to your printer rather than use a cable. There are wireless USB ports and wireless keyboards and mice. The convenience of wireless is what makes it so popular.

CELL PHONES

Are cell phones really a wireless hobby? I say yes as there is a subset of wireless subscribers who play around with cell phones. Again, it is the end use that attracts people to this technology. You can get cell phones with Internet connections and email, instant messaging, video, music (MP3) players, cameras, and games. Wireless Bluetooth headsets are very common. On the way is more TV and something called near field communications (NFC). NFC is short-range communications using a smart card to charge tickets or products to a credit card, for example. NFC helps automatically link Bluetooth and Wi-Fi units. And don't forget those PCMCIA plug-in cards for laptops. They use cell phone service to provide Internet access for laptops.

REMOTE CONTROL

Remote control of model planes started decades ago, and extends to model cars, boats, and robots. Most hobbyists are in it for the models rather than the wireless, but in any case, it is an exciting combination.

HOME MONITORING AND CONTROL

You probably already have some form of this technology, such as with a garage door opener or TV remote control. Most sensors in security systems are wireless rather than wired.

X10 provides a lot of wireless control products. Wireless monitoring and control systems that use Z-Wave or ZigBee make adding lighting control and other features fast and easy. The new M2M (man to machine or machine to machine) applications are a great place to start experimentation.

GENERAL EXPERIMENTING

As mentioned before, there are still those who like to build wireless equipment, modify it, or add to its capability. There are lots of wireless modules using the ISM (industrial scientific medical) bands (315, 433, 902-928 MHz) for general-purpose wireless use. These modules are transceivers with mostly digital input and output using ASK/OOK or FSK modulation. You can plug them into a breadboarding socket and use them to make almost anything else wireless.

Building a wireless thermometer for outdoors is a great project using this technology. Adding remote control to your robot is a good one, too.

Amateur radio receivers and transmitters, SW receivers, and receivers for aircraft, marine, and weather are available as kits. If you've never built any electronic equipment, kits are a great place to start.

GPS (Global Positioning System) is another hot hobby attraction. GPS navigation receivers are cheaper than ever and provide fun in experimenting with location. The hobby of geocaching is a growing one. Teams use GPS handhelds to find caches of buried "treasure" hidden by others.

WRAP-UP

Today, wireless as a hobby is all about the applications. There are many ways to dig deeper into the technology itself if you want. *Nuts & Volts Magazine* is a great source. Also check out *SERVO Magazine* and *Circuit Cellar Magazine* for regular wireless coverage.

If you'd like to become the ultimate wireless hobbyist, be a ham. With access to huge chunks of the frequency spectrum, hams can build and experiment with all kinds of wireless gear.

There is a ton of wireless fun to be had out there, so why not jump on the "band" wagon? **NV**

ELECTRONET

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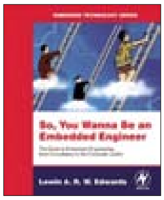
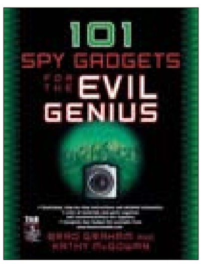
ELECTRONICS

So You Wanna Be an Embedded Engineer
by Lewin Edwards



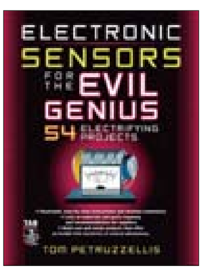
In this new, highly practical guide, expert embedded designer and manager Lewin Edwards answers the question, "How do I become an embedded engineer?" Embedded professionals agree that there is a treacherous gap between graduating from school and becoming an effective engineer in the workplace, and that there are few resources available for newbies to turn to when in need of advice and direction. This book provides that much-needed guidance for engineers fresh out of school, and for the thousands of experienced engineers now migrating into the popular embedded arena. **$39.95**

101 Spy Gadgets for the Evil Genius
by Brad Graham/Kathy McGowan



Utilizing inexpensive, easily-obtainable components, you can build the same information gathering, covert sleuthing devices used by your favorite film secret agent. Projects range from simple to sophisticated and come complete with a list of required parts and tools, numerous illustrations, and step-by-step assembly instructions. **$24.95**

Electronic Sensors for the Evil Genius — 54 Electrifying Projects
by Thomas Petruzzellis



Nature meets the Evil Genius via 54 fun, safe, and inexpensive projects that allow you to explore the fascinating and often mysterious world of natural phenomena using your own home-built sensors. Each project includes a list of materials, sources for parts, schematics, and lots of clear, well-illustrated instructions. Projects include rain detector, air pressure sensor, cloud chamber, lightning detector, electronic gas sniffer, seismograph, radiation detector, and much more. **$24.95**

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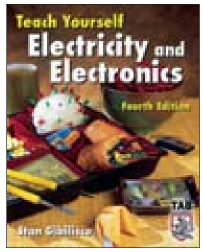
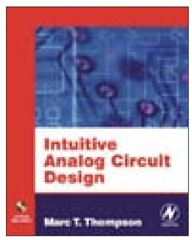
Teach Yourself Electricity and Electronics — Fourth Edition
by Stan Gibilisco



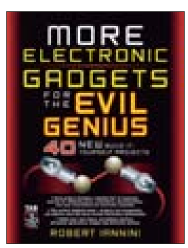
Learn the hows and whys behind basic electricity, electronics, and communications without formal training. The best combination self-teaching guide, home reference, and classroom text on electricity and electronics has been updated to deliver the latest advances. Great for preparing for amateur and commercial licensing exams, this guide has been prized by thousands of students and professionals for its uniquely thorough coverage ranging from DC and AC concepts to semiconductors and integrated circuits. **$34.95**

Intuitive Analog Circuit Design
by Marc Thompson



This book introduces analog circuit design with a minimum of mathematics. It gives readers an intuitive "feel" for analog circuit operation and rules-of-thumb for their design. The author uses numerous analogies from digital design to help readers whose main background is in digital make the transition to analog design. The application of some simple rules-of-thumb and design techniques is the first step in developing an intuitive understanding of the behavior of complex electrical systems. This book outlines some ways of thinking about analog circuits and systems that hopefully develops such "circuit intuition" and a "feel" for what a good, working analog circuit design should be. **$59.99**

MORE Electronic Gadgets for the Evil Genius
by Robert E. Iannini



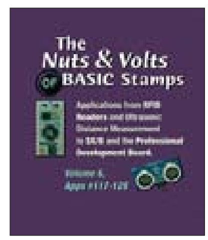
This much anticipated follow-up to the wildly popular cultclassic *Electronic Gadgets for the Evil Genius* gives basement experimenters 40 all-new projects to tinker with. Following the tried-and-true Evil Genius Series format, each project includes a detailed list of materials, sources for parts, schematics, documentation, and lots of clear, well-illustrated instructions for easy assembly. Readers will also get a quick briefing on mathematical theory and a simple explanation of operation along with enjoyable descriptions of key electronics topics. **$24.95**

MICROCONTROLLERS

Programmable Logic Controllers — Fourth Edition
by W. Bolton

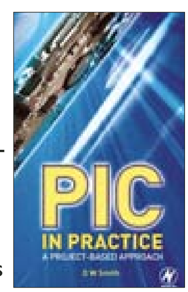
Now in its fourth edition, this best-selling text has been expanded with increased coverage of industrial systems and PLCs and more consideration has been given to IEC 1131-3 and all the programming methods in the standard. The new edition brings the book fully up to date with the current developments in PLCs, describing new and important applications such as PLC use in communications (e.g., Ethernet — an extremely popular system), and safety — in particular proprietary emergency stop relays (now appearing in practically every PLC based system). **$34.95**

Nuts & Volts of BASIC Stamps — Volume #6
by Jon Williams



Nuts & Volts of BASIC Stamps — Volume 6 includes articles #117-128, written for 2005. Article topics consist of RFID Readers and Ultrasonic Measurement, SX/B and the Professional Development Board, the advanced MIDI receiver, programming the SX microcontroller in BASIC, mastering the MC14489 display driver, and more! The Nuts & Volts of BASIC Stamps books are a favorite Parallax technical pick and are a tremendous technical resource for all PBASIC programming projects. **$14.95**

PIC in Practice
A Project-based Approach
Second Edition
by David W. Smith



PIC in Practice is a graded course based around the practical use of the PIC microcontroller through project work. Principles are introduced gradually, through hands-on experience, enabling students to develop their understanding at their own pace. The book can be used at a variety of levels and the carefully graded projects make it ideal for colleges, schools, and universities. Newcomers to the PIC will find it a painless introduction, whilst electronics hobbyists will enjoy the practical nature of this first course in microcontrollers. **$29.95**

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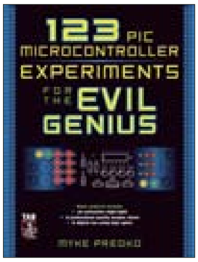
123 PIC Microcontroller Experiments for the Evil Genius
by Myke Predko



Microchip continually updates its product line with more capable and lower cost products. They also provide excellent development tools. *123 PIC Microcontroller Experiments for the Evil Genius* uses the best parts, and does not become dependent on one tool type or version, to accommodate the widest audience possible. Building on the success of *123 Robotics Experiments for the Evil Genius*, as well as the unbelievable sales history of *Programming and Customizing the PIC Microcontroller*, this book will combine the format of the evil genius title with the following of the microcontroller audience for a sure-fire hit. **$24.95**

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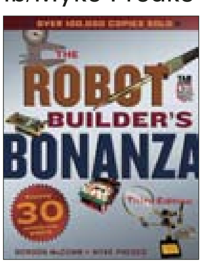
The Evil Genius format is the perfect "vehicle" for 50 incredible automotive projects that are compatible with any car, no matter what make, model, or year. Focusing on low-cost, easily obtained components, *50 Awesome Auto Projects for the Evil Genius* lists the items needed to complete each project along with a troubleshooting and repair section. **$24.95**

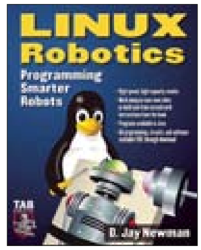
ROBOTICS

Robot Builder's Bonanza Third Edition
by Gordon McComb/Myke Predko



Everybody's favorite amateur robotics book is bolder and better than ever — and now features the field's "grand master" Myke Predko as the new author! Author duo McComb and Predko bring their expertise to this fully-illustrated robotics "bible" to enhance the already incomparable content on how to build — and have a universe of fun — with robots. Projects vary in complexity so everyone from novices to advanced hobbyists will find something of interest. Among the many editions, this book features 30 completely new projects! **$27.95**

Linux Robotics
by D. Jay Newman



If you want your robot to have more brains than microcontrollers can deliver — if you want a truly intelligent, high-capability robot — everything you need is right here. *Linux Robotics* gives you step-by-step directions for "Zeppo," a super-smart, single-board-powered robot that can be built by any hobbyist. You also get complete instructions for incorporating Linux single boards into your own unique robotic designs. No programming experience is required. This book includes access to all the downloadable programs you need, plus complete training in doing original programming. **$34.95**

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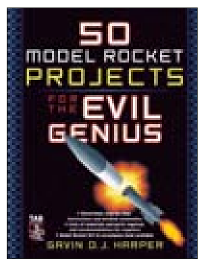


The fun, hands-on way to learn about rocket science. Yes, as a matter of fact, is IS rocket science! And because this book is written for the popular Evil Genius format, it means you can learn about this fascinating and growing hobby while having fun creating 50 great projects. You will find a detailed list of materials, sources for parts, schematics, and lots of clear, well-illustrated instructions. **$24.95**

HOME COMPUTING

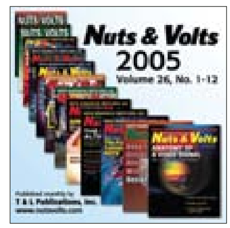
PC Upgrading and Troubleshooting QuickSteps
by Kirk Steers

This low-priced, fast reference uses color screenshots and brief instructions to show and explain how to fix all kinds of PC problems. Each chapter's "How to" list and color coded tabs make it easy to flip straight to specific tasks, such as routine maintenance, start-up issues, drive, monitor, and peripheral problems, Internet connections, upgrading, and more. Useful tips, reminders, shortcuts, and cautions are displayed in the margins so they don't break the flow of the book. **$16.99**

SERVO CD-Rom

Are you ready for some good news? Along with the first 14 issues of *SERVO Magazine*, all issues from the 2005 calendar year are now available, as well. These CDs include all of Volume 1, issues 11-12, Volume 2, issues 1-12, and Volume 3, issues 1-12, for a total of 26 issues all together. These CD-ROMs are PC and Mac compatible. They require Adobe Acrobat Reader version 6 or above. Adobe Acrobat Reader version 7 is included on the discs. **$24.95 – Buy 2 or more at $19.95 each**

Nuts & Volts CD-Rom



Here's some good news for *Nuts & Volts* readers! Along with all 12 issues of *Nuts & Volts* from the 2004 calendar year, the 2005 issues are now available, as well. These CDs include all of Volumes 25 and 26, issues 1-12, for a total of 24 issues (12 on each CD). These CD-ROMs are PC and Mac compatible. They require Adobe Acrobat Reader version 6 or above. Adobe Acrobat Reader version 7 is included on the discs. **$24.95 – Buy 2 or more at $19.95 each**

AUDIO

Self on Audio — Second Edition
by Douglas Self

Whether you are a dedicated audiophile who wants to gain a more complete understanding of the design issues behind a truly great amp, or a professional electronic designer seeking to learn more about the art of amplifier design, there can be no better place to start than with the 35 classic magazine articles collected together in this book. Douglas Self offers a tried and tested method for designing audio amplifiers in a way that improves performance at every point in the circuit where distortion can creep in – without significantly increasing cost. **$44.95**

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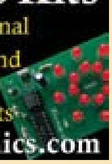

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Continued from page 6

a point of transistor usage which may have been partly lost due to the passing of time and development of newer devices for switching purposes.

To answer the questions you posed in the article, consider the following:

1. The ohmmeter cannot directly measure resistance. It must use Ohm's law with voltages and currents, and provide an answer based on R = V/I. In other words, the ohmmeter provides a known current, and measures the voltage developed as the current passes through the resistor. The voltage is proportional to resistance (V = I*R), so the measured voltage reading is converted to resistance if the current is fixed.

2. When you turn on the base-to-emitter junction, you create the possibility of passing electrons from the emitter to the collector, in normal usage of the NPN transistor. The barrier to electron flow is removed, and there is no reason to expect that you could not also pass them backwards, which is what you do when you set up the meter with reverse polarity leads. Nothing says that you cannot use the transistor in an inverted mode, since you can read "NPN" the same way, forwards or backwards! This point is not made in most semiconductor theory books, because it has not occurred to most technical people to even consider the situation.

3. The resistance curves are probably correct. You have demonstrated a phenomenon which was exploited in the early days of transistor usage. Someone saw the same thing you saw, and added a bit of insight, in that this was a common connection for use in precision analog switches. With transistor switches biased in the normal manner, the V_{ce} saturation voltages were typically 100 mV; they varied with temperature and caused great errors in circuits which needed to switch small voltages. With the transistor operated in the reverse direction, the V_{ce} saturation voltage was an order of magnitude lower, allowing the switch to be more accurate.

4. The first operational amplifiers were made with discrete components. A common configuration for best accuracy (initially with vacuum tubes) is a circuit which converts a DC signal into an AC signal by chopping it up with a switch, then amplifying the AC signal to the desired voltage level. Finally, a second switch — synchronized to the first one — puts the signal back together. This synchronous modulator-demodulator provided better stability, back when a hot transistor had a beta of 20 to 50, and manufacturing processes could not guarantee repeatability between components.

5. To summarize, the inverted connection is a circuit which had its time in the sun, and is not used anymore (or is it?). The physics of transistors can be explored in more detail to understand why the inverted connection has lower on-resistance, but with the advent of D-MOS FETS, and the newer MESFETs, the on-resistance is so low that this circuit has mostly been retired. Sorry that this is so long-winded. Thanks again, for an interesting article.

Tom Patrick
ITT Technical Institute
Woburn MA

TECH FORUM

This is a READER-TO-READER Column.

All questions *AND* answers are submitted by *Nuts & Volts* readers and are intended to promote the exchange of ideas and provide assistance for solving problems of a technical nature. Questions are subject to editing and will be published on a space available basis if deemed suitable by the publisher. Answers are submitted by readers and NO GUARANTEES WHATSOEVER are made by the publisher. The implementation of any answer printed in this column may require varying degrees of technical experience and should only be attempted by qualified individuals. Always use common sense and good judgement!

All questions and answers should be sent by email to forum@nutsvolts.com All *diagrams should be computer generated and sent with your submission as an attachment.*

QUESTIONS

To be considered, all questions should relate to one or more of the following:

1. Circuit Design
2. Electronic Theory
3. Problem Solving
4. Other Similar Topics

- Be brief but include all pertinent information. If no one knows what you're asking, you won't get any response (and we probably won't print it either).
- Include your Name, Address, Phone Number, and email. Only your Name, City, and State will be published with the question, but we may need to contact you.
- No questions will be accepted that offer equipment for sale or equipment wanted to buy.
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ANSWERS

- Include in the subject line of your email, the question number that appears directly below the question you are responding to.
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- Comments regarding answers printed in this column may be printed in the Reader Feedback section if space allows.

>>> QUESTIONS

I've noticed recently some very bright LEDs hitting the market. I was wondering that since these LEDs need 1 watt at about 3VDC, it would be perfect for a photovoltaic system. I'm looking for a circuit diagram and parts list for something that will change 12VDC to 3VDC. Also, I will need the same for a switching system that will turn on a line charger when the batteries get low and a recommendation as to battery type to use.

#10061 **Alan Slate**
via email

I am a relative newcomer in the world of electronics (especially digital). I have enjoyed reading *Nuts & Volts* magazine, though there are many questions that go along with the reading. Could someone please explain why all electronic schematics require ground and what exactly ground means?

I would also appreciate a book recommendation for beginners on how to read a schematic diagram. I built a simple transistor radio a while ago, so I am more or less familiar with how the individual basic components work.

#10062 **Gene**
via email

Has anyone used or reviewed the Cold Heat gadget that one sees advertised on TV, as it pertains to the electronics hobbyist, especially an absolute beginner like myself?

#10063 **Barbara Mathews**
via email

I need an alternator regulator circuit that will allow me to charge a 36-volt and a 72-volt battery bank using a standard automobile alternator (75-100 amp type alternator). Any ideas?

#10064 **Alan Turof**
via email

I have a battery charger that had what appears to be red cardboard between the bottom side of the printed circuit board and the case. What is its purpose? Is this just cardboard or some special insulating material?

#10065 **Richard Lambert**
via email

>>>> ANSWERS

[#8061 - August 2006]

I have a 1989 Lincoln Town Car. I cannot play the AM radio due to excessive ignition noise. Any good suggestions for quelling this noise?

#1 Curing AM radio ignition noise starts with good ignition wires. Two Internet sites provide some information on this, far too extensive to repeat here. The URLs are: **www.land-and-sea.com/dyno-tech-talk/rfi-troubleshooting.htm**

www.magnecor.com/magnecor1/truth.htm

There is an additional possibility that can be mentioned here: On some Ford cars of that era, noise was produced by the fuel pump, located inside the gas tank. Ford recognized the problem and released TSBs (technical service bulletins) on it. You can determine if it applies to your '89 Town Car this way:

"**1.** Turn on the radio before the key is turned on (assuming the radio will operate without the ignition key — you may need to put the ignition key in the Accessory position).

2. Turn the ignition key to the Run position (do not start the engine).

3. The fuel pump should run for about one second with the key in the Run position with the engine not running. Listen for noise in the radio. If noise is present while the pump is running and stops when the pump stops, then the noise is being generated by the pump and this procedure should help."

The quoted information is from **www.arrl.org/tis/info/fuel.html**

I had this problem on a '91 Grand Marquis, and was able to cure it with a large feed-through capacitor installed in the trunk, and a toroid choke in the trunk on the wires to the pump.

Ed Schick
Harrison, NY

#2 Many possibilities exist for AM radio noise in an older car. If the engine has a distributor with a cap and rotor — as some still did in 1989 — check for carbon or excessive wear on the rotor and the contacts in the cap. I saw many old and new cars with that problem. Check the plug wires for cracking and dirty contacts. Modern ignition systems are so powerful that you may not notice a drop in engine performance even though the plug wires are in tatters.

Grounding at almost any point can deteriorate over the years. Check where the antenna mounts to the fender. Power antennas are especially suspect. Check the antenna wire for melting or nicks which may be a sign of corrosion on the shield. The fender itself — in particular if there has ever been body work — could be poorly grounded through corrosion on the fasteners. Check the computer module for grounding and corrosion on the connector plugs, especially if it happens to be under the carpet where moisture can collect. The antenna cable and connector at the radio, as well as the radio chassis ground, are possibilities. Some faults in the charging system (alternator, regulator, battery) can sound like ignition noise. A dried up filter cap or circuit board crack in the radio can as well.

A helpful troubleshooting aid is a portable AM radio. If the ignition noise is radiating anywhere within 20 feet of the car, you can pretty much eliminate the car radio and the antenna wiring as the cause. Good luck.

John Smith
via email

#3 Some very good information on automobile RFI (radio frequency interference) and how to combat it can be obtained on the National Association for Amateur Radio (ARRL) website at **www.arrl.org/tis/info/rfiignit.html**

Also, you should consider bonding your vehicle's metal parts to cut down on the ignition noise. Bonding is connecting together loose or moving metal parts of the vehicle with grounding braid. These areas are doors, hood and trunk lids, and any other areas where metal parts may rub. Rubbing metal parts can cause excessive noise in your car's radio. You should be able to purchase the gounding braid at any auto supply store or stereo shop that specializes in auto electronics.

Ralph J. Kurtz
Old Forge, PA

#4 If the radio is original, the noise must be coming in the antenna. If it is an after-market radio, perhaps it needs additional filtering on the power lead. You can get a hash filter from RadioShack that should solve the problem. In any case, check that the grounding strap for the hood is intact and making good contact (look for rust and corrosion). If the ignition wires are copper, change to resistor wire. Also, check the spark plug gap; an excessive gap will make the noise worse.

Russell Kincaid
Milford, NH

#5 You need to replace the condenser (capacitor) in your distributor. Its job is to suppress the ignition noise caused by the opening and closing of the ignition points. Even in newer cars with an electronic ignition, the condenser is used to suppress noise. Your local auto parts store should have one.

Daryl Rictor
via email

#6 The noise in the AM radio of the 1989 Town Car can come from two sources:

(1) 12VDC power supply, or **(2)** antenna. Try these troubleshooting techniques.

Remove the antenna from the rear of the radio; start the car. If noise persists, it's coming from the 12VDC input and it's likely "alternator whine." RadioShack once had an inductor/capacitor kit (cheap) to put in the DC line to filter out the whine. If they no longer carry the thing, try a truck stop or CB shop because originally RS sold the kit to get noise out of CB radios.

However, if the noise goes away when the antenna is removed, noise is coming from the sparkplug wires and/or the plugs. Try putting in new RFI spark plug wires (typically, graphite wires of about 10K ohm resistance) and replacing the plugs with "resistor" type plugs. See your auto parts dealer for the proper spark plug type. Both changes will cut down the EMI radiated from wiring and plugs that the radio's antenna is picking up.

Cliff Appel
Cheyenne, WY

#7 Carefully check your antenna and coax for opens and shorts with an ohmmeter. I have had water get into my coax from the antenna and dissolve the center lead. If the water contains any salt, it can also cause a short circuit to ground. Also, it would be helpful to connect a capacitor of about 0.1 microfarads to each of the radio's power supply leads, or an

interference filter. You should be able to find items made for this purpose at your local auto supply store.

Owen Mayer
Hoffman Estates, IL

[#8062 - August 2006]

I have a Stanley remote controlled garage door opener model ST 500 that no longer responds to remote signals. The batteries in the remotes have been replaced and code switches are set correctly. I have checked and reset the code switches on the receiver twice — no help. The opener works fine with the push button. Does anyone have a schematic of the radio signal receiver section (or other help)?

#1 While not being able to locate a schematic for the receiver section of the garage door opener, there is a website that you can go to that sells replacement receivers for Stanley garage door openers: **www.1stdooropeners.com/stanley/receivers.htm**

They have several replacement receivers available that can replace your ST 500 receiver.

Ralph J. Kurtz
Old Forge, PA

#2 My guess is the oscillator in either the remotes or the main receiver in the Stanley ST-500 garage door opener has drifted. The oscillator in the remote is a cheap and simple LC circuit that only needs "retweaking" after a few years.

Try this with one remote opener before attacking the receiver in the door opener. By the way — make sure the antenna is still attached to the receiver and that it hasn't broken off. Open a remote and you should see a form about an inch long and about as thick as a lead pencil with about three or four turns around it. It should be hollow with a gray ferrite slug inside.

This is the "L" part of the LC oscillator in the remote. Get a non-metallic "tweaker" (typically, plastic with a hex head on it) that will fit inside the ferrite slug. Put a piece of tape as a "flag" near the middle of the tweaker so you can keep track of how far you're turning the ferrite slug. My tweaker is a left-over tool from an old Heathkit radio of 30 years ago, so try a ham radio operator or Heathkit builder to see if he/she has one you can borrow.

Stand out in front of your garage with the remote and insert the tweaker in the ferrite slug. Hold down the remote's button and then rotate the ferrite slug first in one direction for about a turn. If the door moves you're going in the right direction.

If it doesn't, put the ferrite slug back where you started ... now you see why you need the tape "flag" on the tweaker. Hold down the button on the remote again and rotate the slug in the opposite direction you turned originally. If the door operates at some point, you need to fine-tune the remote. If it doesn't, my guess might be the receiver in the opener is bad.

If tweaking gets the door to open, then you need to find the optimum tuning for the remote's oscillator. Walk further away from the garage door until the button on the remote will no longer operate the door. Tweak the ferrite slug a wee bit more until the door operates. Keep doing this as you walk further away from the door.

At some point, you'll reach a spot where the opener won't open the garage door no matter how much tweaking you do. Then, walk a bit closer to the garage and tweak again to get the garage door to operate. At this point, it's about as good as it's going to get, but if you're 40 or 50 feet away from the garage door, that's good enough.

Cliff Appel
Cheyenne, WY

[#8063 - August 2006]

I have the sixteenth edition of Transistor Substitution Handbook, published by Howard Sam's Company in 1976.

It appears that books like this are no longer in print. Do you know of a website database for this purpose?

#1 You can find cross-references for numerous transistors here: **www.ee.washington.edu/circuit_archive/parts/cross.html**

Another site that crosses a transistor part to the NTE replacement: **http://nte01.nteinc.com/nte/NTExRefSemiProd.nsf/$$Search?OpenForm**

Ed Schick
Harrison, NY

#2 Try using the Google Search Engine. Enter the component 'ID' and/or product manufacturer and you will most likely get a .pdf file with all the data you'll need on the component. I use this method quite frequently and it works just fine.

John F. Mastromoro
St. Johnsville, NY

#3 For database programs available online, check out these two websites. They are both sources for database programs for semiconductor substitutions: **www.softlookup.com/display.asp?id=2894** or **http://shareware.pcmag.com/product.php[id]45178[cid]93[SiteID]simtel.net**

Ralph J. Kurtz
Old Forge, PA

#4 There are not so many transistors used today as there were 30 years ago, and there are so many new numbers, I don't expect to see any compilation of cross-references for current devices.

When I want to find a transistor, I use Digi-Key's search engine (**www.digikey.com**). Here is how it works: Enter "transistor" in the part search, you will then be able to select the type you want: FETs, IGBT, Obsolete (you don't want those), RF, Arrays, or Transistors (bipolar). If you select transistors, the next page gives you a choice of: Current Rating, Package/Case, Transistor Type, or Voltage Rated. If you choose all four, you most likely won't get a match, but you can select a range of parameters to improve the chance of a match. If the transistor you want is not found, try a higher current and/or voltage rating.

If the transistor you are looking for is not too old, Mouser may suggest a replacement (**www.mouser.com**). Or, Mouser may have it in stock!

Russell Kincaid
Milford, NH

AD INDEX

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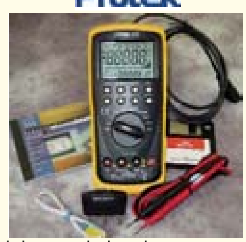

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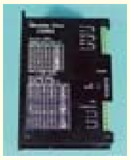
85BYGH350C-03	NEMA 34	63kg.cm/874oz.in	$119.95

Stepper Motor Controllers 2 Phase Microstepping

Stepper Motor Driver (Bi-polar & Unipolar Motors)



Part #:	Dimensions:	MicroStep:	Price:
XCW220	100mm x 61mm x 19mm	1(200), 1/2(400), 1/4(800), 1/8(1600)	$39.95
CW220	99mm x 65mm x 30mm	1/2(400), 1/8(1600)	$49.95
CW230	115mm x 72mm x 32mm	1(200), 1/2(400), 1/4(800), 1/8(1600), 1/16(3200), 1/32(6400), 1/64(12800)	$59.95
CW250	140mm x 94mm x 45mm	1(200), 1/2(400), 1/8(1600)	$69.95
CW860	147mm x 97mm x 30mm	1(200), 1/2(400), 1/4(800), 1/8(1600), 1/16(3200), 1/32(6400), 1/64(12800), 128(25600), 1/5(1000), 1/10(2000), 1/25(5000), 1/50(10000), 1/125(25000), 1/250(50000)	$119.95

Protek 20MHz Dual Trace Oscilloscope

- 20MHz Bandwidth
- Alt-Mag sweep for simultaneous display of main and X5 magnified trace
- 1mV/Div Vertical sensitivity
- Alternate trigger for a stable display of unrelated signals
- Multi-level trigger
- X5 Sweep Magnification

Item# PROTEK 6502 $279.00!

Details at Web Site

> Test Equipment > Oscilloscopes/Outstanding prices

Digital Storage Oscilloscope Module

PC based Digital Storage Oscilloscope, 200MHz 5GS/s equiv. sampling USB interface

Convert any PC with USB interface to a high performance Digital Storage Oscilloscope. This is a sophisticated PC basedscope adaptor providing performance compatible to mid/high level stand alone products costing much more! Comes with two probes.

Details & Software Download at Web Site

Price Breakthrough!

> Test Equipment > Oscilloscopes/Outstanding Prices

Item# 200DSO Only$749.00

Protek 2MHz Sweep Function Generator

- 0.02Hz-2MHz(7 Ranges)
- Sine,Triangle,Square,Pulse,Ramp, Slewed Sine Waveform
- Sync. Out (TTL Square Waveform)
- Accuracy: ±5% of Full Scale to 200KHz, ±8% of Full Scale from 200KHz-2MHz
- Sweep Function
- VCG Input

Item# PROTEK 9205

Special $159.00! Any Quantity

Details at Web Site

> Test Equipment > Function Generators

SONY Super HAD CCD Color Weatherproof IR Cameras

- Day & Night Auto Switch
- Signal System: NTSC
- Image Sensor:1/3" SONY Super HAD CCD
- Horizontal Resolution: 480TV lines
- Min. Illumination: 0Lux

480 TV Lines Resolution

Item# VC-827D: $132.00

SONY Super HAD CCD™ equipped camera's feature dramatically improved light sensitivity

Intelligent DMM w/ RS-232

- 3999 Counts and 38 Segment Bar Graph
- Dual Display (digits & bar graph)
- Capacitance Function, Transistor & Diode Test
- Frequency Range & Temperature
- RS232C Standard Interface
- Data Hold

Item# CSI345 SALE $29.95

Details at Web Site

> Test Equipment > Digital Multimeters/World Beater Prices

SONY Super HAD CCD B/W Weatherproof IR Camera

- Day & Night Auto Switch
- Signal System: EIA
- Image Sensor: 1/3" **SONY Super HAD CCD**
- Horizontal Resolution: 420TV lines
- Min. Illumination: 0Lux

Item# VC-317D: $59.50

Details at Web Site

SONY Super HAD CCD Color Camera

- Weather Proof
- Signal System: NTSC
- Image Sensor: 1/4" SONY Super HAD CCD
- Horizontal Resolution: 420TV lines
- Min. Illumination: 1Lux/F1.2

Item# VC-805: $53.95

> Miniature Cameras(Board,Bullet,Mini's, B/W, Color)

SONY Super HAD CCD Color Weatherproof IR Camera

- Day & Night Auto Switch
- Signal System: NTSC
- Image Sensor: 1/4" **SONY Super HAD CCD**
- Horizontal Resolution: 420TV lines
- Min. Illumination: 0Lux

Item# VC-819D: $62.50

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